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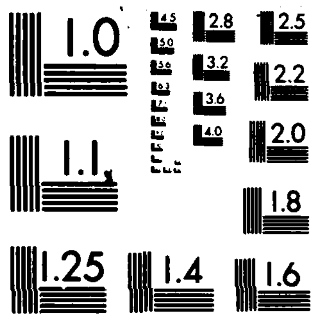

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Bethesda, Maryland 20084

AD-A140 647

A TECHNIQUE FOR SELECTING STABILIZING FINS FOR SWATH SHIPS

By

Ralph Stahl

and

K.K. McCreight

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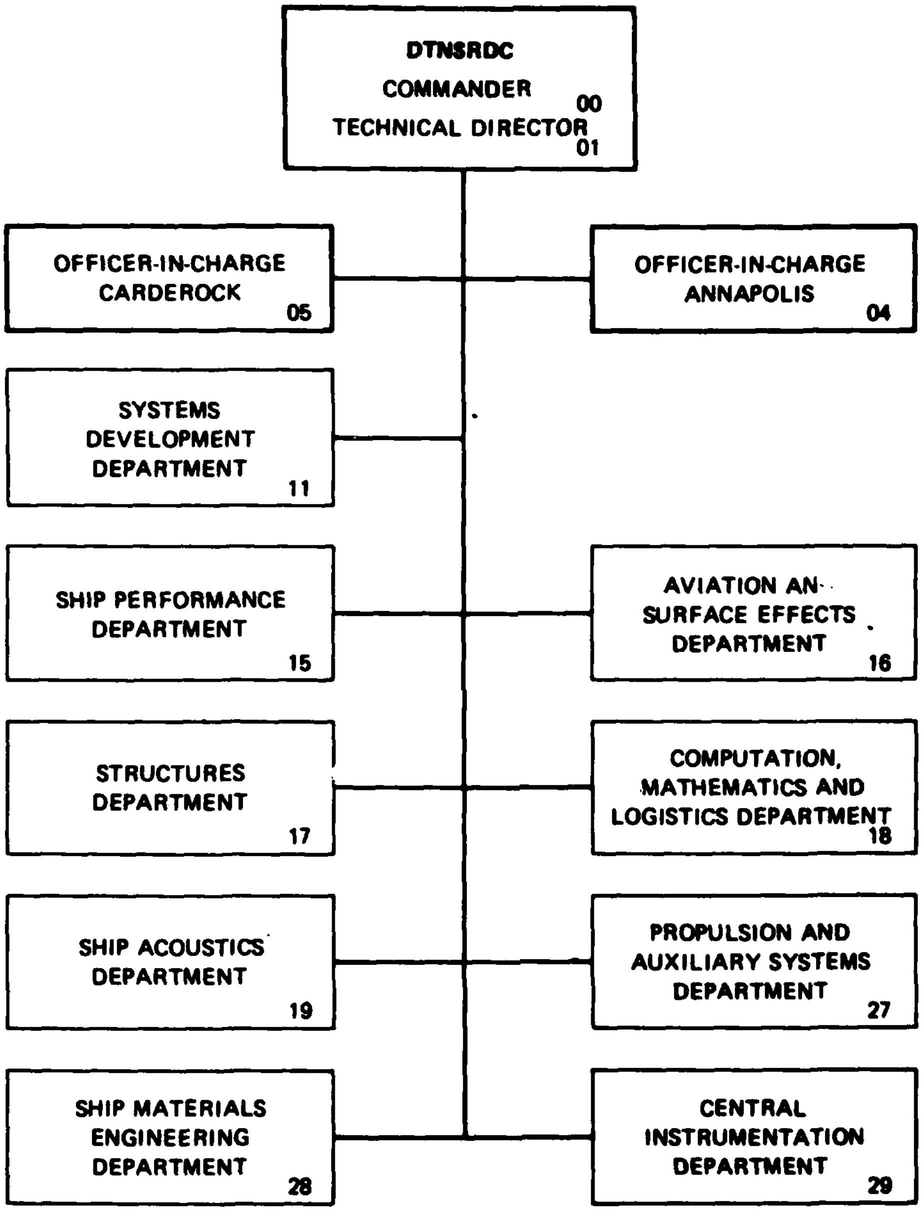

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A computer technique has been developed to select a set of fins for an arbitrary SWATH configuration, providing it with stability and favorable dynamic response characteristics. The design technique is based on an analytical stability determination and evaluation of dynamic responses for an array of fin sets which vary in aft fin to forward fin area distribution and longitudinal fin location. Presented is the fin selection technique with sample results and guidelines helpful to the user. The technique offers an efficient and economical tool for designing

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SWATH stabilizing fins in a technically objective manner.

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NOTATION

A_R	Stern fin area to forward fin area ratio
ASM	Absolute stern motion
A_i	Area under transfer function i.e. $A_i = \int (T.F.)_i \, d\omega_o$. Subscript i refers to heave, pitch, RBM, or ASM
A_{ij}	Added mass coefficient
B_{ij}	Damping coefficient
C_{ij}	Restoring coefficient
GM_L	Longitudinal metacentric height
H_s	Significant wave height
I_5	Ship's moment of inertia in pitch
LCB	Longitudinal center of buoyancy
LCF	Longitudinal center of flotation
LCG	Longitudinal center of gravity
M	Ship mass
N	Number of motion modes
P_{ij}	Normalized motion mode for the i^{th} mode and j^{th} fin set
RBM	Relative bow motion
RMS	Root mean square
$S(\omega_o)$	Sea - energy spectrum
S_{jk}	Relative fin performance index for the j^{th} fin set and k^{th} wave heading
T_o	Modal wave period
T_j	Relative fin performance index for the j^{th} fin set for both head and following waves

T.F.	Transfer function
W_i	Relative motion mode importance factor for the i^{th} motion mode
w_i	Relative wave heading importance factor for the i^{th} heading
β	Relative wave heading with respect to the ship (β = 180 degrees corresponds to head waves)
λ_n	Roots of the coupled heave and pitch equations of motion
ξ_3	Heave displacement transfer function
ξ_5	Pitch displacement transfer function
ξ_{RBM}	RBM transfer function
ξ_{ASM}	ASM transfer function
ω_o	Wave frequency in radians per second

ABSTRACT

A computer technique has been developed to select a set of fins for an arbitrary SWATH configuration, providing it with stability and favorable dynamic response characteristics. The design technique is based on an analytical stability determination and evaluation of dynamic responses for an array of fin sets which vary in aft fin to forward fin area distribution and longitudinal fin location. Presented is the fin selection technique, with sample results and guidelines helpful to the user. The technique offers an efficient and economical tool for designing SWATH stabilizing fins in a technically objective manner.

ADMINISTRATIVE INFORMATION

This work was funded under the Ships, Subs, and Boats Program of NAVSEA, Program Element N62543, Task Area SF 421-350-200. The funding is administered by the Ship Performance Department of the David Taylor Naval Ship Research and Development Center, Bethesda, Maryland.

INTRODUCTION

A small-waterplane-area, twin hull (SWATH) ship consists of two identical submerged hulls with surface-piercing struts connected to a bridging structure above the waterplane. Dynamic characteristics of the ship can be significantly improved with the addition of stabilizing fins. In the analytical approach to SWATH ship motion studies, computational tools have been developed at the David Taylor Naval Ship Research and Development Center (DTNSRDC) to predict the dynamic responses of SWATH ships. Previously, the task of designing a set of stabilizing fins for a given SWATH has involved a cumbersome, time consuming process of evaluating a series of fins varying in size and longitudinal location. The present work substantially automates the iterative process of selecting a set of stabilizing fins by means of a computer program. For a given ship configuration and operating conditions the total fin area and fin aspect ratios are fixed; fin pairs resulting from the combination of four potential area distributions and three longitudinal locations for the forward and aft fins are investigated. The evaluation is dependent on ship speed and wave heading; consequently, the series of fin sets is evaluated at a specified design speed and in either head or following waves or both. Only the fin sets providing ship stability and acceptable natural periods of oscillation in heave and pitch at either the design speed or at some specified speed greater than the design speed are considered. From the acceptable fin sets, the set providing the ship with the most favorable dynamic characteristics at the design speed in either head or following waves or both is selected as the best fin set. The selection does not represent an optimum fin set but does represent the best fin set amongst those investigated, and can provide guidance for further fin design improvements.

APPROACH TO FIN SELECTION TECHNIQUE

A technique has been developed to select a set of inboard, passive, rectangular planform, stabilizing fins which minimize motion responses of a twin-hull ship for specified operating conditions. This technique was implemented by incorporating fin performance and stability algorithms in SSEP (SWATH Seakeeping Evaluation Program), a DTNSRDC computer program which predicts the motions of SWATH ships in sinusoidal waves and in long-crested irregular waves [1,2*]. Fin sets are defined as a fin forward of the ship's longitudinal center of gravity (LCG) and one aft of the LCG, or a single aft fin mounted on the inboard maximum breadth curve of the hull. A matrix of stabilizing fin sets is generated usually with four fin area distributions and three longitudinal locations for each of the forward and aft fins. The set has a user supplied total fin area and specified fin aspect ratios. The aft-fin-to-forward-fin area ratio, A_R , if not specified, defaults to a dynamically reasonable fin area distribution range from 1.5 to 6.0. Quasi-calm water stability utilizing frequency dependent hydrodynamic coefficients of the SWATH ship in heave and pitch both without fins and with each fin set is determined. Unstable fin sets, as well as those with unreasonably long natural heave or pitch periods at the design speed or a specified greater speed are deleted from further consideration. The remaining fin sets are evaluated with regard to their dynamic characteristics at the design speed in regular head and/or following waves, and if desired, in a Bretschneider or Pierson-Moskowitz wave spectrum. Utilizing these dynamic response data, the present technique based upon a response weighting function was developed to select the best fin set for the SWATH configuration investigated.

*References are listed on page 15

STABILIZING FIN SET GENERATOR

All discrete fin sets considered for selection generally consist of a passive fin forward of the LCG and a passive fin aft of the LCG. A modified and optional case includes fin sets consisting only of an aft fin and no forward fin. All fins are mounted on the inboard maximum breadth line of the hull and lie in the horizontal plane. Generally a matrix of 36 stabilizing fin sets, as shown schematically in Table 1a is generated from the following: specified total fin area, fin aspect ratio, the forwardmost location of the forward fin's leading edge, the aftmost location of the aft fin's trailing edge, and four aft fin to forward fin area ratios (A_R). If not specified, the values of A_R are set to equal 1.5, 2.6, 4.2, and 6.0. The 36 fin sets are therefore a combination of three forward fin locations, three aft fin locations and four aft fin to forward fin area ratios, A_R . Fin sets in which the forward fin and aft fin occupy the same space either longitudinally or transversely are eliminated from further consideration. Table 1b shows a schematic of a modified fin set matrix with some single fin cases. Only three A_R's are specified, with the fourth A_R indeterminate since there is no forward fin. Consequently, the total number of fin sets in Table 1b reduces to 30 with the elimination of duplicate sets.

SHIP STABILITY

The quasi-calm water stability of the SWATH ship without fins and with each fin set is determined for all specified speeds. Stability characteristics for the fin design study are confined to the vertical plane, dealing with the coupled heave and pitch equations of motion with frequency dependent coefficients but without excitation forces (declining oscillation case) as formulated by C.M. Lee and M. Martin[3]. These equations are as follows:

$$(M+A_{33})\ddot{\xi}_3 + B_{33}\dot{\xi}_3 + C_{33}\xi_3 + A_{35}\ddot{\xi}_5 + B_{35}\dot{\xi}_5 + C_{35}\xi_5 = 0 \qquad (1)$$

$$A_{53}\ddot{\xi}_3 + B_{53}\dot{\xi}_3 + C_{53}\xi_3 + (I_5 + A_{55})\ddot{\xi}_5 + B_{55}\dot{\xi}_5 + C_{55}\xi_5 = 0 \qquad (2)$$

where ξ_3 = heave

ξ_5 = pitch

and the superscript dots denote the first and second time derivatives

The objective is to determine whether the ship in calm water has sufficient stability at a given forward speed to return to its original equilibrium within a reasonable time after being momentarily disturbed from that equilibrium.

Formulation of the hydrostatic and hydrodynamic coefficients in the computer code is described in References 1 and 2. Since most of the coefficients are frequency dependent, a choice was made of selecting the value of the coefficients at a frequency close to the heave resonance frequency for stability computation, a procedure utilized and justified in Reference 3. With the heave and pitch equations (1) and (2) as a pair of linear, homogeneous differential equations with constant coefficients, roots are obtained from the characteristic equation. The four roots ,λ_n, may be real or complex, with complex roots appearing as conjugate pairs. Inspection of the roots leads to four possible kinds of normal modes of motion[3]. These stability criteria are:

1. If λ_n is real and positive, the motion is divergent and thus unstable.
2. If λ_n is complex with a positive real part, the motion is divergent and oscillatory and thus unstable.
3. If λ_n is real and negative, the motion is convergent and thus stable.
4. If λ_n is complex with a negative real part the motion is convergent and oscillatory and thus stable.

Matching the roots obtained for coupled heave and pitch motion is accomplished with a comparison of the periods obtained in the coupled mode to the periods obtained from the uncoupled equations of motion as in Reference 3.

Normally, unappended SWATH ships become less stable with increasing forward speed. An acceptable fin set on a given SWATH must not only satisfy criterion 4 above for heave and pitch at the design speed or specified higher speed, but should also have reasonable heave and pitch periods. An upper bound for the heave and pitch natural periods is a variable which is defined in the input data. Two minutes is used in this study.

MOTION RESPONSES

Motion transfer functions are computed at the design speed for the unappended hull, if stable, and for all stable fin sets[1]. The relative wave heading, β, can be specified as either 180 deg (head waves) or 0 deg (following waves) or both headings.

Optionally, the series of stable fin designs can be evaluated with the utilization of irregular wave responses expressed by the root mean square, RMS, as follows:

$$RMS_i^2 = \int_0^\infty (\bar{\xi}_i)^2 \; S(\omega_o)\, d\omega_o$$

where $(\xi_i)^2$ = response amplitude operator of the i^{th} mode of motion

$S(\omega_o)$ = sea energy spectrum as a function of wave frequency

The number of wave spectra that can be used for the fin design study is presently limited to a single two parameter Bretschneider spectrum which varies with significant wave height and modal period. The spectrum can be expressed in the form:

$$S(\omega_o) = \frac{C_1}{\omega_o^5} \exp\left(-C_2 / \omega_o^4\right)$$

where $C_1 = 487.06\, H_s^2 / T_o^4$

$C_2 = 1948.24 / T_o^4$

H_s = significant wave height in meters

T_o = modal wave period in seconds

If a modal period is not specified, a one parameter Pierson-Moskowitz wave spectrum is assumed. This spectrum is a special case of the Bretschneider spectrum with the modal wave period defined as

$$T_o = \sqrt{7.6219\ H_s}$$

The wave spectrum used to evaluate the series of stable fins should correspond to the most frequently occurring wave height and modal period in a particular geographical local. For the sample fin design studies in this report, a one-parameter Pierson-Moskowitz wave spectrum with a significant wave height of 2.4 meters was used as representative of the North Atlantic sea environment[4]. A recommended alternative for the same area is a Bretschneider spectrum with a 3.1 meter significant wave height and 9.0 second modal period[5]. This corresponds to a Sea State 5, the most probable sea state in the North Atlantic, with a 42 percent chance of occurrence.

SELECTION TECHNIQUE

Choosing the fin set with the most favorable dynamic response from the series of stable fin sets for the design speed and a given wave heading might involve, in the simplest form, a visual inspection of the heave, pitch, RBM, and ASM transfer functions (T.F.'s) and RMS responses in irregular waves. This approach makes it difficult to select a fin set objectively.

A reasonable refinement to the above approach is to characterize the transfer functions by their integrals (i.e., area under the T.F.) and the maximum response amplitudes of motion modes. From a data base which includes the irregular wave RMS motion responses in addition to the T.F., a relative fin performance index, S_{jk}, can be computed for the j^{th} stable fin set at the k^{th} wave heading of β=180 deg or 0 deg as follows:

$$S_{jk} = \left[\frac{1}{N} \sum_{i=1}^{N} (W_i)(P_{ij})\right]_k$$

where N = number of motion elements (6 in regular waves, plus 4 in irregular waves if irregular waves are used)

W_i = relative linear weight for the i^{th} element

P_{ij} = motion element for the j^{th} fin normalized by the maximum of the elements with fixed i and all values of j.

The best fin set, j, corresponds to the minimum value of S_{jk} at a given wave heading k. This correspondence occurs because a value of S_{jk}, a function of P_{ij}, is directly proportional to the dynamic response of the j^{th} fin set for the i^{th} motion mode. The weighting factor series, W_i, is the same series for each fin set. The P_{ij} are calculated from:

1. Area under the heave transfer function $\xi_3 (\omega_o)$: $A_3 = \sum_{i=1}^{n} \xi_3 (\omega_o)_i (\Delta\omega_o)_i$

   where ω_o is the wave frequency, and n is the number of discrete wave frequencies examined.

2. Area under the pitch transfer function $\xi_5(\omega_o)$, $A_5 = \sum_{i=1}^{n} \xi_5 (\omega_o)_i (\Delta\omega_o)_i$

3a. Area under the relative bow motion (RBM) transfer function $\xi_{RBM} (\omega_o)$: at station 0,

$$A_{RBM} = \sum_{i=1}^{n} \xi_{RBM} (\omega_o)_i (\Delta\omega_o)_i$$

3b. Maximum amplitude of the RBM transfer function $\xi_{RBM|MAX}$

4a. Area under the absolute stern motion (ASM) transfer function $\xi_{ASM}(\omega_o)$: at station 20,

$$A_{ASM} = \sum_{i=1}^{n} \xi_{ASM} (\omega_o)_i (\Delta\omega_o)_i$$

4b. Maximum amplitude of the ASM transfer function $\xi_{ASM|MAX}$,

where 3a and 3b are equally weighted as well as 4a and 4b.
If irregular wave responses are utilized, the following additional motion factors are used to evaluate the series of stable SWATH ship fin sets:

5. Root mean square heave displacement (RMS_3)

6. Root mean square pitch displacement (RMS_5)

7. Root mean square relative vertical bow displacement (RMS_{RBM})

8. Root mean square absolute vertical stern displacement (RMS_{ASM})

The weight, W_i, supplied by the user serves as a relative importance factor for the i^{th} motion mode compared to the other motion modes. For example, if all motion modes are of equal relative importance, a value of 1.0 may be assigned to each W_i with $i = 1$ to 8. If a motion mode is to be deleted altogether, a value of zero may be assigned to the particular W_i. Note that the components of P_{ij} given above include the areas under the T.F. for all modes of motion as well as the maximum regular wave response amplitude for RBM and ASM. The weight W_i assigned to either RBM or ASM is divided equally between the area under the T.F. and the maximum amplitude of the T.F. If, for example, the user defines the weight for RBM, W_3, to be 1.0, the computer code will define the weights of 0.5 to both the area under the RBM T.F. and to the maximum amplitude of the RBM T.F. With regard to heave, pitch, RBM, and ASM, the values assigned to W_i are primarily mission dependent. The relative importance of irregular wave to regular wave responses is dependent upon objectives of the investigation although an emphasis on irregular wave responses is recommended since they characterize the ship's dynamics in a realistic seaway. This can be of particular importance for responses with a narrow banded T.F. if the T.F. peak is close to the modal wave frequency. Also, considering regular wave responses only, the areas under two T.F.'s may be equal; however, in irregular waves the T.F. which has its peak coincident with the modal wave frequency is clearly a bad choice.

If both headings are used in selecting a fin set, evaluation of all stable fin sets is performed for each heading, resulting in two arrays S_{j1} and S_{j2}, one for each heading. Each of the two arrays is normalized by the maximum array element, $S_{jk/max}$ for a given heading, k, and noted as S_{j1}' and S_{j2}'. This procedure assures a degree of equalization of the array elements between the two wave headings. Finally, the two headings are combined for each stable fin set j as follows:

$$T_j = \sum_{k=1}^{2} w_k \, S_{jk}'$$

The fin performance index, T_j, and heading weight, w_k, are analogous to the single heading variables S_{jk} and W_i. Just as for S_{jk}, the best fin, for the two heading case corresponds with T_j of minimum value. The user supplied wave heading importance factor, w_k, is dependent on mission requirements. If both headings are equally important, $w_1 = w_2 > 0$. The weights, W_i, apply equally to either wave heading.

SAMPLE INVESTIGATIONS WITH FIN SELECTION TECHNIQUE

The fin selection technique described above is applied to four SWATH ship hull geometries designated as AA, BB, CC, and DD. The choice provides a variety in both hull geometries and hydrostatic characteristics which presumably would require different fin sets to achieve favorable dynamic characteristics. Figure 1 shows the top view of one of the two identical hulls and struts without stabilizing fins, for each of the four SWATH ships. The struts are prismatic in the vertical direction and the lower bodies are circular in cross section. The pertinent ship particulars are listed in Table 2. Based on a modified technique of defining SWATH ship geometry analytically[6], all four ships are designed from a set of desired parametric values such as: single or tandem strut, strut and hull lengths with maximum transverse dimensions of each, hull separation, overall displacement, waterplane area, draft, longitudinal metacentric height (GM_L), longitudinal center of flotation (LCF), and center of gravity.

The most significant difference between SWATH ships AA and BB with regard to motions is in their longitudinal metacentric height (GM_L). SWATH AA has a GM_L of 5.1 meters, whereas SWATH BB has a GM_L of 42.8 meters. Both SWATH CC and DD have a slight strut overhang of 4.3 meters at the stern. Their main difference is the location of LCB relative to LCF, both of which are measured from the nose of the lower hull. SWATH CC has an LCB-LCF separation of 2.2 meters, whereas SWATH DD has a value of -3.1 meters (a minus sign indicates that LCF is aft of LCB).

The input fin parameters for the four ships are given in Table 3. Fins are evaluated in both head and following waves at a design speed of 20 knots for SWATH's AA, BB, CC, and at 10 knots for SWATH DD. Also included in the evaluation is the optional irregular wave responses for a Pierson-Moskowitz wave spectrum with a significant wave height of 2.4 meters and a 7.8 second modal wave period.

Equal weighting is used for all four ships for each of the following: the four motion modes of heave, pitch, RBM, ASM; both wave types of regular and irregular waves; and both wave headings of β=180 and 0 degrees. The four best fin sets for each of the four ships selected from dynamic considerations of operation in regular waves, irregular waves, a weighted combination of both, for head and following waves are listed in descending order in Table 4. The motion characteristics of the best fin set in each category are presented in Tables 5-8 and graphically in Figures 2-5, for SWATH AA thru DD. As seen in Figures 2-5, significant differences in the transfer functions can occur amongst various fin sets, with even greater differences evident between head and following wave responses.

Also from these tables and figures a general observation can be made that an increase in the number of variables utilized in the fin selection leads to an averaging which tends to a corresponding increase in required compromises. For example, a fin set best suited for minimizing heave in regular head waves may not be suitable for minimizing absolute stern motion. The ensuing fin selection may be a third set which is best for minimizing neither heave nor absolute stern motion individually, but is best when considering both motions. The degree of compromise can sometimes be minimal, as can be seen in Table 4 for SWATH BB in head waves and for SWATH CC in following waves where the same fins were best for the criteria considered separately and for the criteria considered together.

With the same series of fin sets evaluated on SWATH BB as on SWATH AA, and most other ship parameters nearly identical except for GM_L, some comparisons are interesting. SWATH AA with the smaller GM_L performs better in head waves than SWATH BB, and SWATH BB performs better in following waves. This trend is evident from Tables 5 and 6 and Figures 2 and 3 when comparing the transfer function related parameters and RMS responses, particularly in pitch, RBM and ASM.

In addition to the fin design for each of the four ships, two runs were made of SWATH AA with the same series of fin sets as previously used, but with unequal relative weighting of wave heading and motion modes (see Table 9). The first case consists of head wave dynamic responses taken as 4 times more important than following wave responses. The second case considers following waves as 9 times more important than head wave responses. Also, in the second case, absolute stern motion is the only motion considered in regular waves. Table 9 lists the best four fin sets in descending order in the same format as Table 4.

For the first case in Table 9, in which all responses are again weighted equally, fin sets 13 and 6 were selected as best in head and following waves, respectively, just as in Table 4 (see columns labeled "Both" in Tables 9 and 4). However, fin set 21 was chosen best for the combined, unequally weighted headings (see "Overall" column in Table 9). For the previously equally weighted condition, fin set 21 ranked as the 5th best fin set. In the second case, with great importance placed on ASM in following waves, fin set 12 was found to be best overall. When all responses were given equal relative weight, fin set 21 was best overall. This indicates that fin set 12 can be very effective in reducing ASM, whereas fin set 21 is best when some reduction in all motions is desired.

A further attempt at refinement in the selection of a best fin is illustrated with SWATH DD. Referring to Tables 1a and 4, the selection of fin set 28 as being best in irregular head waves suggests a fin set consisting of only an aft fin and no forward fin as a worthy candidate for investigation since the forward fin is already quite small. SWATH DD is therefore re-evaluated upon replacing those fin sets having the largest A_R of 5.0 (Table 3) with a single stern fin as shown schematically in Table 1b. All specifications in Table 3 used previously for the SWATH DD apply to the single fin as for instance its area of 35.74 m^2. The computer program selected fin set did indeed confirm the single stern fin at the aftmost location as the best choice but only with regard to reducing irregular head wave responses. When considered with the remaining equally weighted factors consisting of regular head wave and regular and irregular following wave motion responses, the overall choice as the best fin set from among those evaluated was still number 1 as shown in Table 4. This demonstrates how the algorithm can be utilized to explore alternative designs. Only a discrete set of fins have been considered.

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* Note: The area of a single stern fin is equal to the total area of the two fin sets from which it is derived by eliminating the forward fin.

CONCLUSIONS

An analytical tool to facilitate selection of passive stabilizing fins for a SWATH ship has been presented. Examples included in this report show how the selected fins yield favorable dynamic characteristics for the vessel. The fin selection technique functions within a framework of fin parameters provided by the user. These parameters are: total fin area, forward and aft fin aspect ratios, lower and upper bounds in fin area distribution between forward and aft fins, and forwardmost and aftmost fin locations. Several parametric variations can be explored by the user provided that fin design is not too restrictive. As noted in the introduction, the technique utilized in the fin selection algorithm is not an optimization technique. A discrete set of fin configurations are generated and their relative effectiveness is evaluated. It is unlikely that the optimum set of fins will be among those considered. However, since the set of fins generated and the basis for the ranking are directly related to program input data, a broad range of fin configurations can be evaluated by multiple computer runs.

Seldom is a single fin set best for minimizing all motions. This leads to some degree of compromise if more than one motion parameter (heave, pitch, RBM, and ASM), type of waves (regular and irregular), or wave heading (head and following) are utilized in the fin selection. No compromise exists if only one parameter is used in the fin design study, as for example pitch in a given sea state at one heading. At the other extreme, the degree of compromise can be significant when all parameters are equally weighted; that is, all four motions of heave, pitch, RBM, and ASM, in both regular and irregular waves, and both head and following waves receive equal consideration. Consequently, knowledge of the SWATH ship mission requirements should be used to determine appropriate weights for the relative importance of the parameters listed above. One recommendation we would like to make is the selection of weights that emphasize irregular wave response characteristics since these correspond more closely to a natural sea environment. A suggested significant wave height and modal wave period for the two-parameter Bretschneider wave spectrum used in the irregular wave fin evaluation are 3.1

meters and 9.0 sec. respectively[5]. This corresponds to Sea State 5, the most probable sea state in the North Atlantic Basin.

Manually selecting a fin set from the motion transfer functions for a series of fin designs would not only be tedious and time consuming, but subjective to a large extent. The analytic tool presented here greatly reduces the required effort in designing SWATH ship stabilizing fins in terms of time and expense. Even more important, the technique vastly reduces the subjectivity that would otherwise be inherent in the fin selection process.

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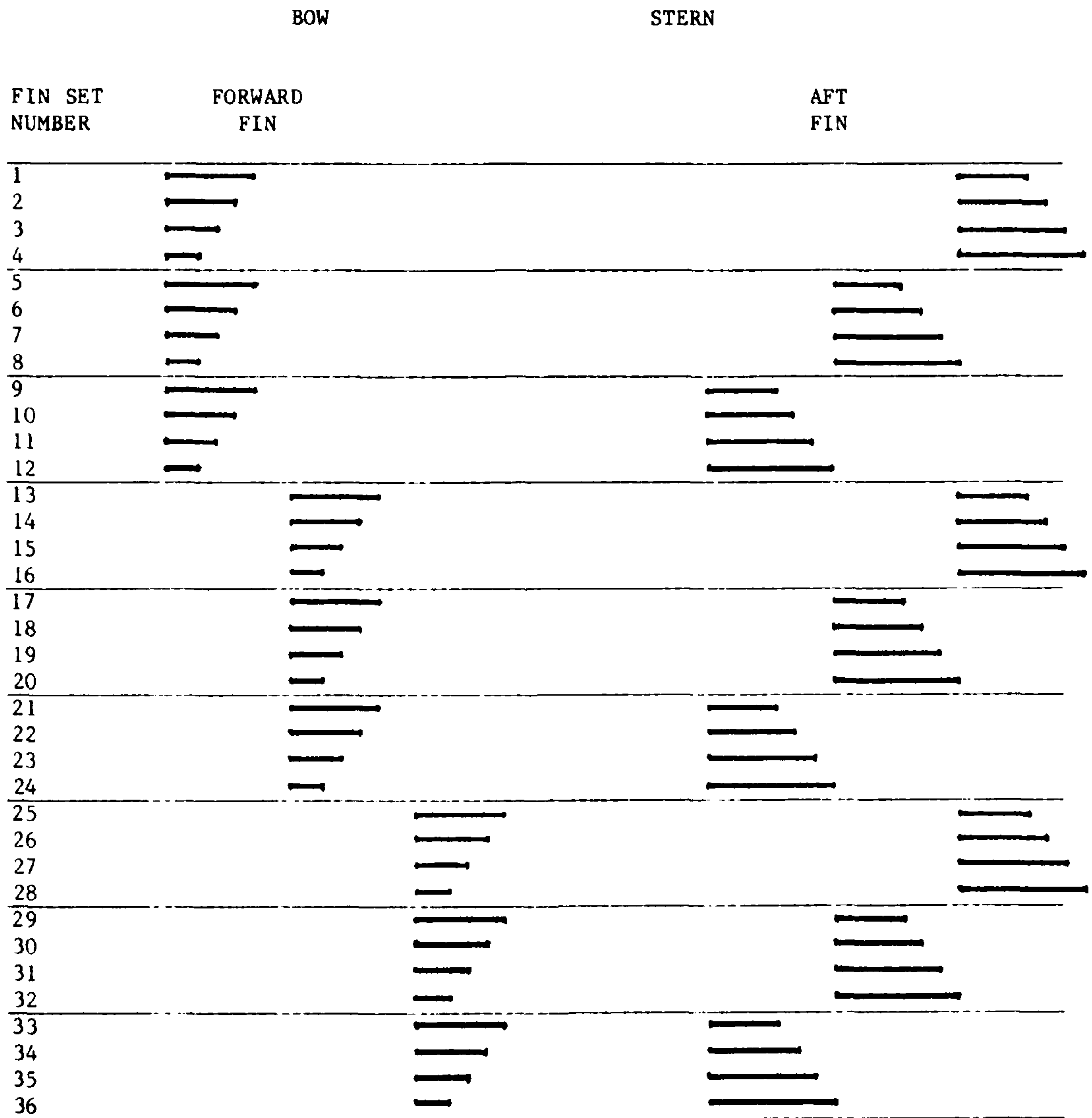
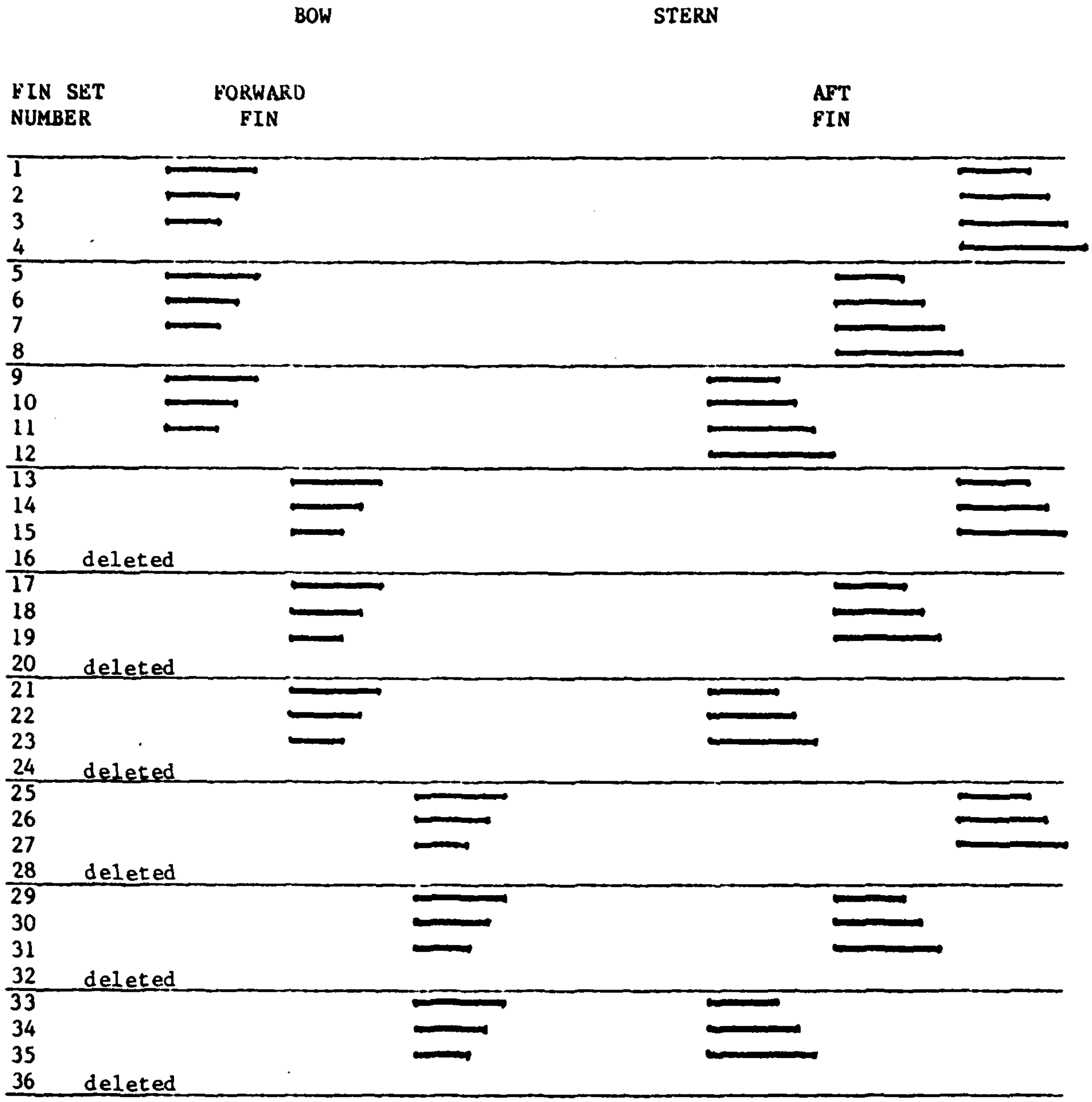
TABLE 1 - Schematic of Fin Location and Area Distribution for the Series of Generated Fin Sets



FIN AREA EQUIVALENT TO LENGTH OF LINE

TABLE 1a - Fin Sets Consisting of Forward and Aft Fins



FIN AREA EQUIVALENT TO LENGTH OF LINE

TABLE 1b - Fin Sets Consisting of Forward and Aft Fins and some Single Aft Fins

TABLE 2 - SWATH Particulars

	UNITS	SWATH AA	SWATH BB	SWATH CC	SWATH DD
LENGTH OVERALL (LOA)	METERS	51.06	51.06	65.84	65.84
LENGTH AT WATERLINE	METERS	54.86	68.58	60.78	60.78
MAXIMUM HULL DIAMETER	METERS	3.83	3.93	5.92	5.72
NO. OF STRUTS PER HULL		1	2	1	1
MAXIMUM STRUT THICKNESS (FORWARD/ AFT)	METERS	2.22	3.93/3.93	2.39	2.39
DRAFT	METERS	6.31	6.41	8.66	8.46
CENTERPLANE TO CENTERPLANE HULL SEPARATION	METERS	20.52	19.23	23.47	23.47
DISPLACEMENT	METRIC TONS	1831.	1979.	3165.	3148.
WATERPLANE AREA	M^2	152.00	182.60	222.50	221.95
LONGITUDINAL CB FROM LOWER HULL NOSE	METERS	33.57	33.35	34.51	35.30
LONGITUDINAL CF FROM LOWER HULL NOSE	METERS	30.35	31.72	32.31	38.36
LONGITUDINAL GM	METERS	5.07	42.83	11.09	10.99
TRANSVERSE GM	METERS	2.44	2.44	3.51	3.39
KG	METERS	9.14	9.14	10.36	10.36
KB	METERS	2.60	2.77	3.91	3.77
PITCH RADIUS OF GYRATION	METERS	16.46	16.46	18.29	18.29
ROLL RADIUS OF GYRATION	METERS	10.45	10.45	12.19	12.19

TABLE 3 - Input Fin Parameters per Hull

PARAMETER	UNITS	SWATH			
		AA	BB	CC	DD
TOTAL AREA (FWD AND AFT FIN)	M	18.58	18.58	35.74	35.74
MINIMUM FORWARD FIN LEADING EDGE TO HULL NOSE DISTANCE	METERS	6.10	6.10	1.62	1.62
MAXIMUM STERN FIN TRAILING EDGE TO HULL NOSE DISTANCE	METERS	63.70	63.70	59.07	59.07
FORWARD FIN ASPECT RATIO		1.20	1.20	1.41	1.41
STERN FIN ASPECT RATIO		1.20	1.20	1.41	1.41
MINIMUM AFT FIN AREA TO FORWARD FIN AREA RATIO A		1.5	1.5	2.0	2.0
MAXIMUM AFT FIN AREA TO FORWARD FIN AREA RATIO A		3.0	3.0	5.0	5.0

TABLE 4 - Four Best Fin Sets in Descending Order of Performance for Various Criteria with Equal Weighting of Heave, Pitch, RBM, and ASM in Regular and Irregular Waves and in Head and Following Waves for SWATH AA, BB, CC, and DD.

SWATH SHIP	CRITERIA						
	HEAD WAVES			FOLLOWING WAVES			OVERALL FOR BOTH HEADINGS
	TRANSFER FUNCTIONS	RMS	BOTH	TRANSFER FUNCTIONS	RMS	BOTH	
AA	12*	26	13	6	12	6	12
	21	25	3	7	6	7	6
	22	27	14	8	7	12	33
	2	28	4	12	8	8	7
BB	1	1	1	16	25	28	15
	2	2	2	15	26	26	14
	3	3	3	28	28	27	16
	4	5	5	27	27	25	13
CC	1	28	1	11	11	11	11
	5	27	2	9	9	9	9
	9	26	3	10	12	12	1
	2	25	4	5	10	10	5
DD	1	28	3	5	9	9	1
	2	27	4	9	5	5	5
	3	26	2	1	10	1	6
	13	25	1	6	1	10	9

* Fin Set Number

TABLE 5 - SWATH AA Motion Transfer Function Characteristics and RMS Responses in 2.4 Meter Significant Wave Height Irregular Seas at 20 Knots for Several Fin Designs

WAVE HEADINGS	HEAD WAVES (β=180 DEG)				FOLLOWING WAVES (β= 0 DEG)			
FIN SET NUMBER	12	6	13	26	12	6	13	26
AREA UNDER HEAVE T.F.	0.59	0.58	0.59	0.63	0.93	0.85	1.08	0.96
AREA UNDER PITCH T.F.	0.39	0.41	0.45	0.53	0.79	0.89	1.20	1.20
AREA UNDER RBM T.F.	1.86	1.84	1.92	2.01	1.91	1.70	2.93	2.90
AREA UNDER ASM T.F.	0.65	0.67	0.60	0.56	1.95	1.83	2.37	2.45
RBM T.F. MAXIMUM	1.77	1.77	2.04	2.53	3.10	1.77	3.42	3.74
ASM T.F. MAXIMUM	1.17	1.24	1.18	1.11	2.23	2.16	3.06	3.25
HEAVE RMS (METERS)	0.11	0.10	0.10	0.10	0.31	0.29	0.42	0.37
PITCH RMS (DEGREES)	0.20	0.22	0.16	0.14	1.37	1.53	2.38	2.49
RBM, RMS (METERS)	0.62	0.61	0.63	0.62	0.75	0.70	1.53	1.62
ASM, RMS (METERS)	0.20	0.21	0.17	0.16	0.88	0.97	1.32	1.38

NOTES: RBM = Relative Bow Motion, ASM = Absolute Stern Motion

TABLE 6 - SWATH BB Motion Transfer Function Characteristics
and RMS Responses in 2.4 Meter Significant Wave Height
Irregular Seas at 20 Knots for Several Fin Designs

WAVE HEADINGS	HEAD WAVES (β=180 DEG)					FOLLOWING WAVES (β= 0 DEG)				
FIN SET NUMBER	15	1	16	25	28	15	1	16	25	28
AREA UNDER HEAVE T.F.	0.66	0.60	0.66	0.68	0.69	0.72	0.90	0.73	0.83	0.84
AREA UNDER PITCH T.F.	0.78	0.69	0.78	0.83	0.82	0.71	0.80	0.70	0.71	0.70
AREA UNDER RBM T.F.	2.08	1.94	2.09	2.14	2.15	1.30	1.58	1.28	1.09	1.14
AREA UNDER ASM T.F.	0.83	0.78	0.83	0.87	0.86	1.12	1.25	1.12	1.16	1.14
RBM T.F. MAXIMUM	2.18	1.60	2.25	2.57	2.67	1.35	2.12	1.30	1.14	1.18
ASM T.F. MAXIMUM	1.61	1.53	1.62	1.79	1.75	1.26	1.79	1.22	1.29	1.14
HEAVE RMS (METERS)	0.18	0.13	0.18	0.20	0.21	0.22	0.29	0.23	0.24	0.25
PITCH RMS (DEGREES)	0.56	0.47	0.56	0.62	0.59	0.89	1.19	0.88	0.89	0.85
RBM, RMS (METERS)	0.89	0.79	0.89	0.93	0.92	0.52	0.73	0.51	0.42	0.44
ASM, RMS (METERS)	0.31	0.26	0.31	0.33	0.32	0.52	0.63	0.52	0.53	0.50

* NOTES: RBM = Relative Bow Motion, ASM = Absolute Stern Motion

TABLE 7 - SWATH CC Motion Transfer Function Characteristics and RMS Responses in 2.4 Meter Significant Wave Height Irregular Seas at 20 Knots for Several Fin Designs

WAVE HEADINGS	HEAD WAVES (β=180 DEG)				FOLLOWING WAVES (β= 0 DEG)			
FIN SET NUMBER	11	1	28		11	1	28	
AREA UNDER HEAVE T.F.	0.57	0.54	0.64		0.73	0.87	0.83	
AREA UNDER PITCH T.F.	0.60	0.54	0.86		0.82	1.17	1.39	
AREA UNDER RBM T.F.	1.98	1.90	2.23		1.69	2.35	3.37	
AREA UNDER ASM T.F.	0.53	0.54	0.46		1.69	2.19	2.83	
RBM T.F. MAXIMUM	2.06	1.78	3.68		1.72	3.61	7.83	
ASM T.F. MAXIMUM	1.22	1.29	1.08		1.95	2.67	6.09	
HEAVE RMS (METERS)	0.09	0.07	0.09		0.19	0.33	0.29	
PITCH RMS (DEGREES)	0.13	0.13	0.09		1.60	2.46	3.70	
RBM RMS (METERS)	0.65	0.63	0.67		0.70	1.41	2.39	
ASM RMS (METERS)	0.11	0.11	0.08		0.83	1.14	1.82	

NOTES: RBM = Relative Bow Motion, ASM = Absolute Stern Motion

TABLE 8 - SWATH DD Motion Transfer Function Characteristics and RMS Responses in 2.4 Meter Significant Wave Height Irregular Seas at 10 Knots for Several Fin Designs

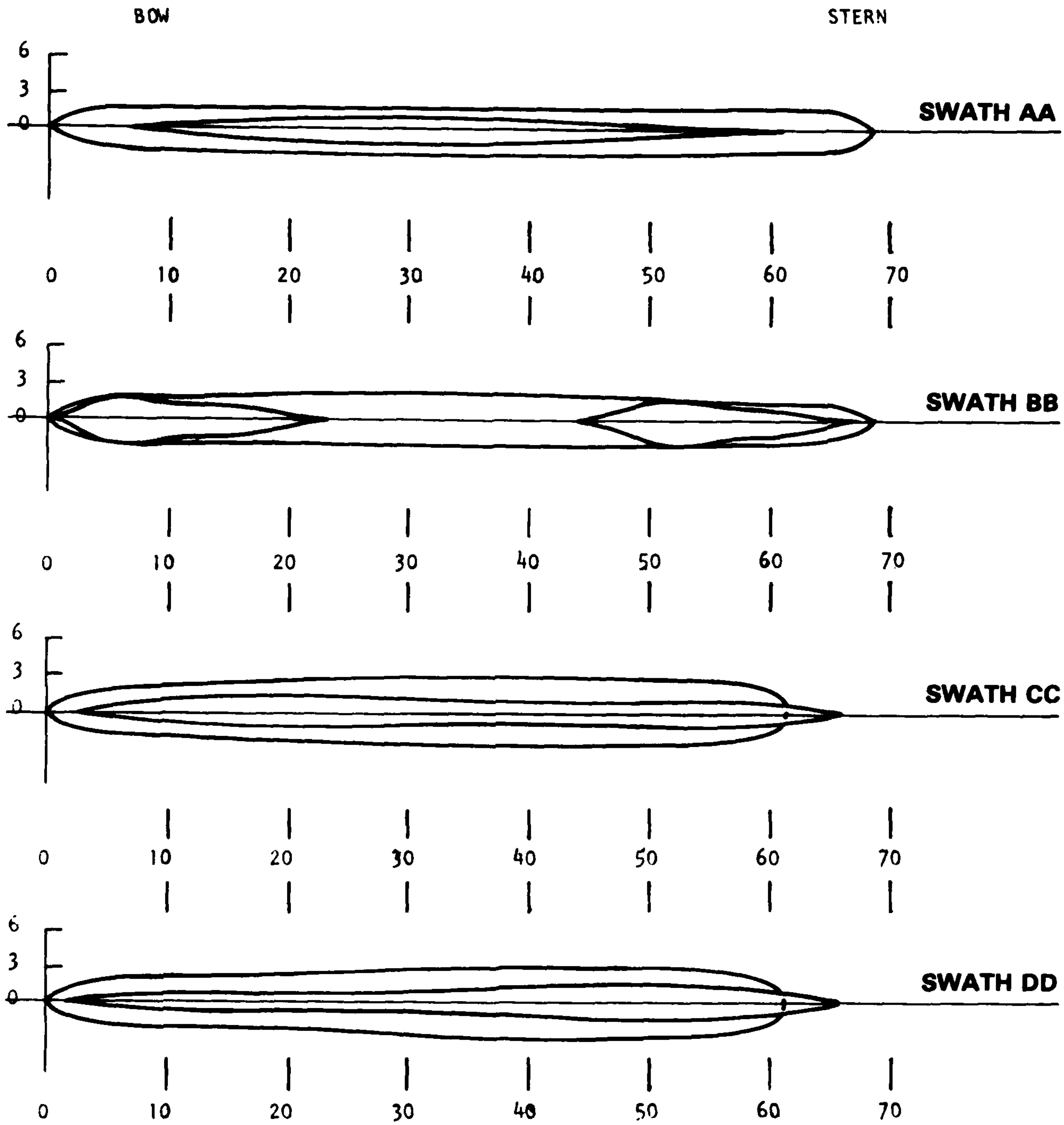
WAVE HEADINGS	HEAD WAVES (β=180 DEG)					FOLLOWING WAVES (β= 0 DEG)				
FIN SET NUMBER	1	3	5	9	28	1	3	5	9	28
AREA UNDER HEAVE T.F.	0.58	0.59	0.59	0.60	0.61	0.74	0.79	0.69	0.68	1.09
AREA UNDER PITCH T.F.	0.64	0.68	0.68	0.70	0.80	1.00	1.09	1.03	1.04	1.38
AREA UNDER RBM T.F.	1.78	1.85	1.77	1.76	1.99	2.97	3.33	2.87	2.99	4.49
AREA UNDER ASM T.F.	0.72	0.69	0.78	0.82	0.66	2.30	2.44	2.26	2.33	2.91
RBM T.F. MAXIMUM	1.39	1.60	1.37	1.43	2.02	3.01	3.54	2.81	3.01	5.30
ASM T.F. MAXIMUM	1.84	1.76	1.96	2.17	1.68	1.55	1.88	1.59	1.60	2.57
HEAVE RMS (METERS)	0.10	0.09	0.10	0.11	0.10	0.21	0.24	0.19	0.16	0.43
PITCH RMS (DEGREES)	0.24	0.22	0.26	0.28	0.18	1.42	1.68	1.37	1.36	2.60
RBM, RMS (METERS)	0.60	0.60	0.60	0.61	0.62	1.01	1.25	0.92	0.91	2.07
ASM, RMS (METERS)	0.19	0.18	0.20	0.22	0.17	0.70	0.79	0.72	0.74	1.06

NOTES: RBM = Relative Bow Motion, ASM = Absolute Stern Motion

Table 9 - Four Best Fin Sets in Descending Order of Performance for Various Criteria with Unequal Weighting of Heave, Pitch, RBM, and ASM in Regular and Irregular Head and Following Waves for SWATH AA.

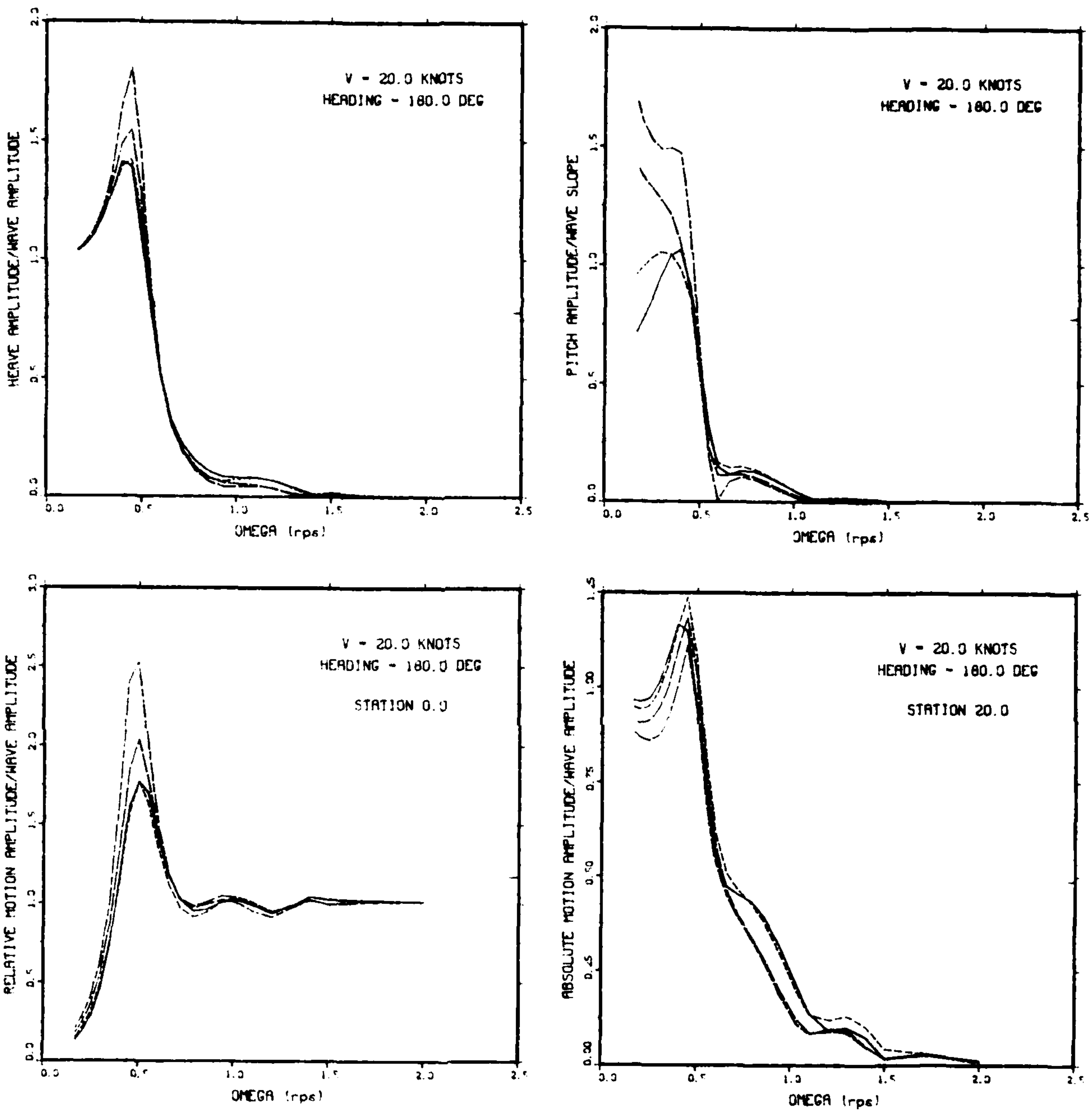
RELATIVE IMPORTANCE FACTOR										CRITERIA						
HEADING (deg)		MOTION MODE								HEAD WAVES			FOLLOWING WAVES			OVERALL FOR BOTH HEADINGS
		REGULAR WAVES				IRREGULAR WAVES				TRANSFER FUNCTIONS	RMS	BOTH	TRANSFER FUNCTIONS	RMS	BOTH	
180	0	HEAVE	PITCH	RBM	ASM	HEAVE	PITCH	RBM	ASM							
1.0	0.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	12*	26	13	6	12	6	21
										21	25	3	7	6	7	33
										22	27	14	8	7	12	13
										2	28	4	12	8	8	3
0.11	1.0	0	0	0	1.0	0.2	0.2	0.2	1.0	27	0**	27	6	12	12	12
										28	25	28	7	6	6	6
										36	26	25	8	7	7	7
										35	27	26	17	33	8	8

* Fin Set Number
** Bare Hull



ALL DIMENSIONS ARE IN METERS

Figure 1 - Top View of SWATH Hull and Strut Geometry for One of Two Identical Sides



FIN SET 12
FIN SET 6
FIN SET 13
FIN SET 26

Figure 2a - SWATH AA Transfer Functions in Regular Head Waves at 20 knots with Specified Fin Sets

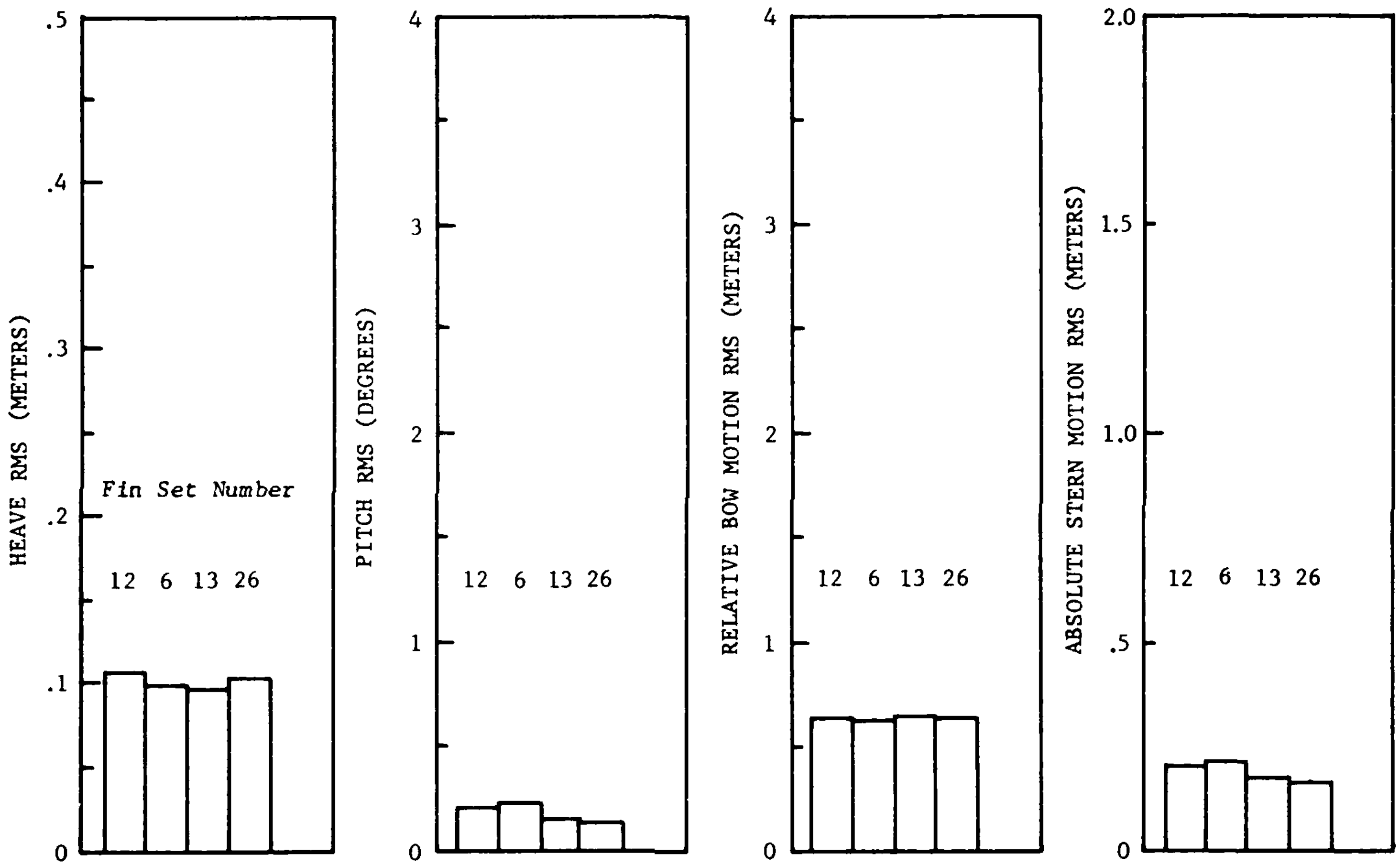


Figure 2b - RMS Responses of SWATH AA at 20 knots with Specified Fin Sets in Irregular Head Waves with Significant Wave Height of 2.4 Meters

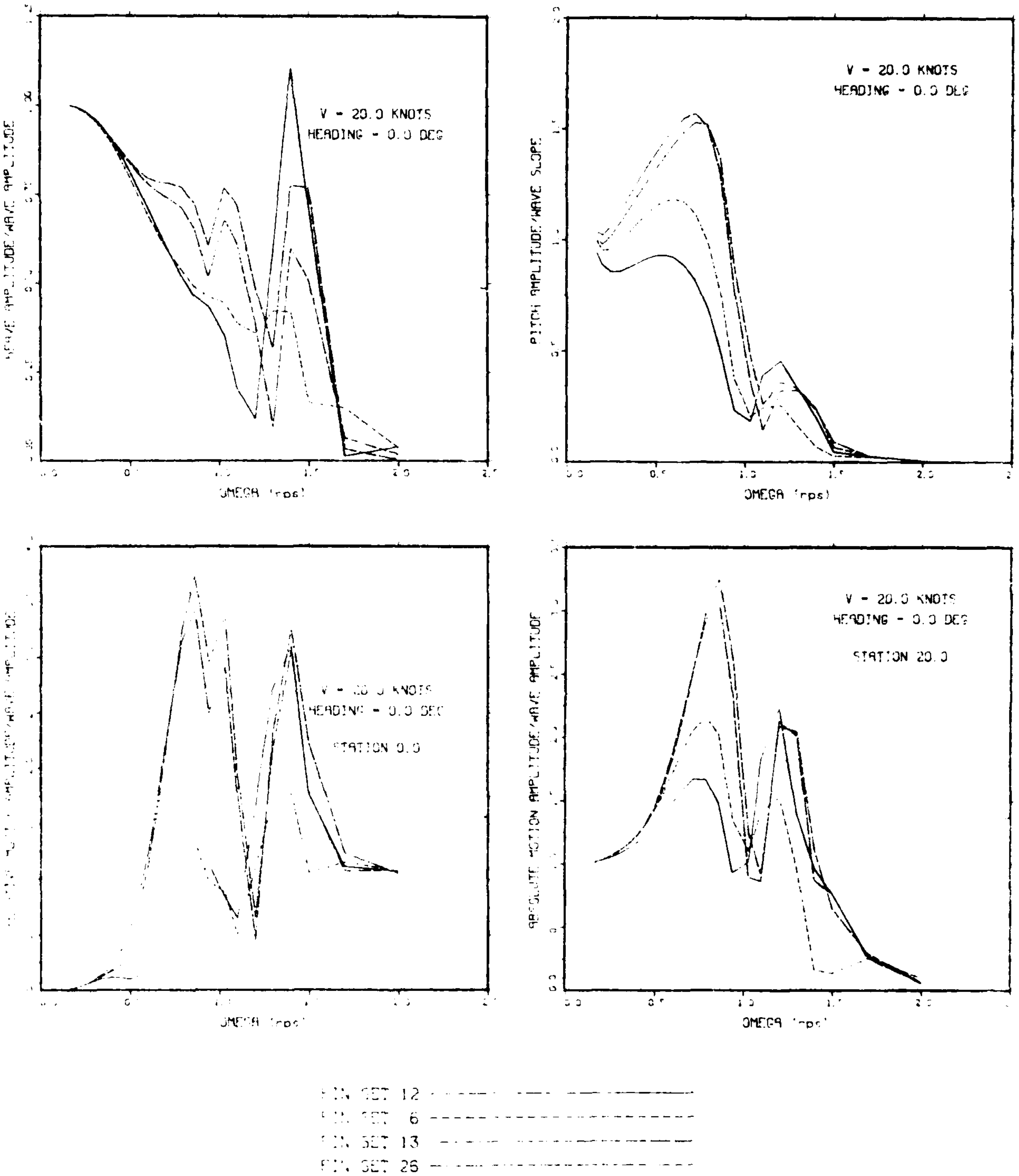


Figure 2c - SWATH AA Transfer Functions in Regular Following Waves at 20 knots with Specified Fin Sets

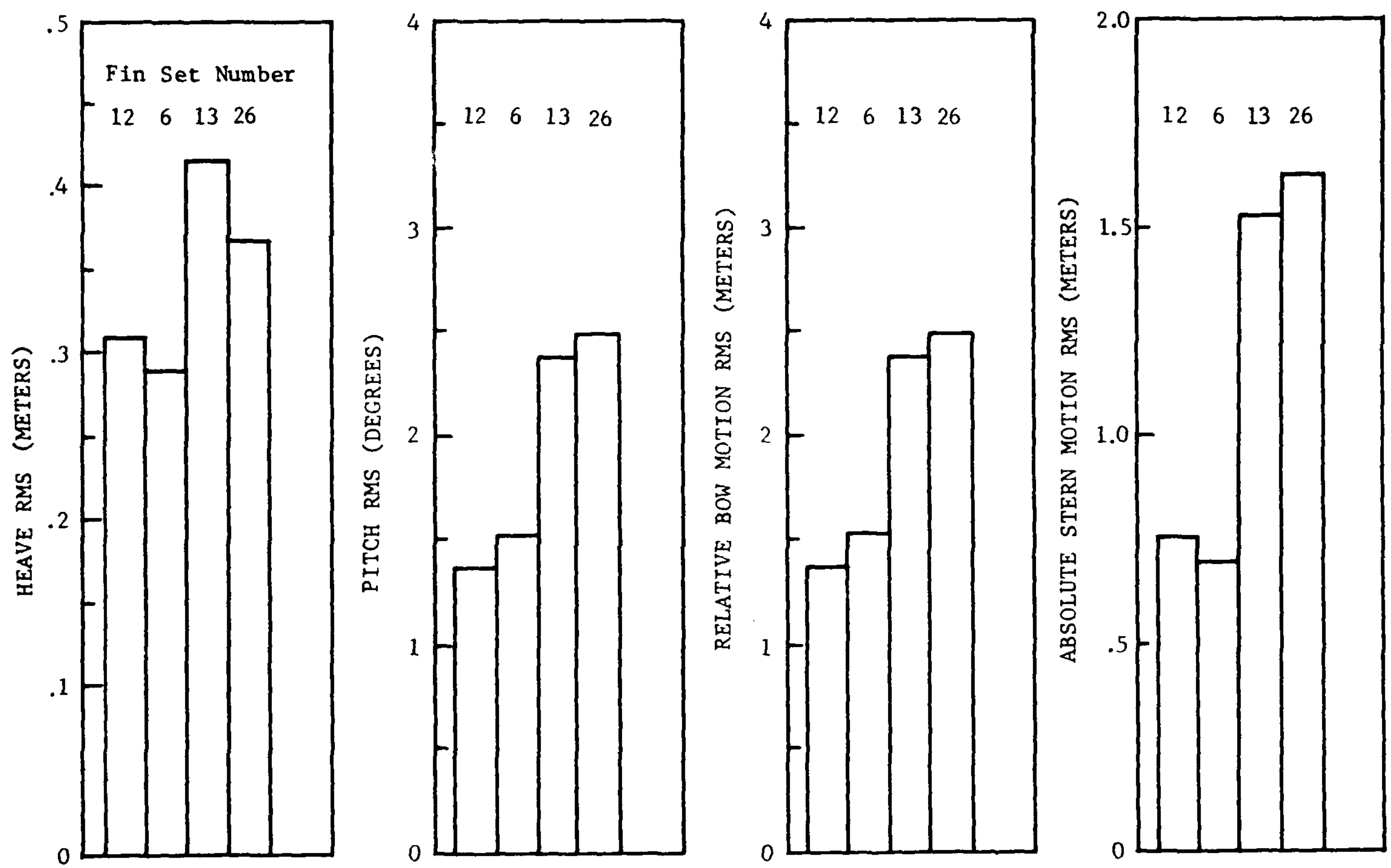


Figure 2d - RMS Responses of SWATH AA at 20 knots with Specified Fin Sets in Irregular Following Waves with Significant Wave Height of 2.4 Meters

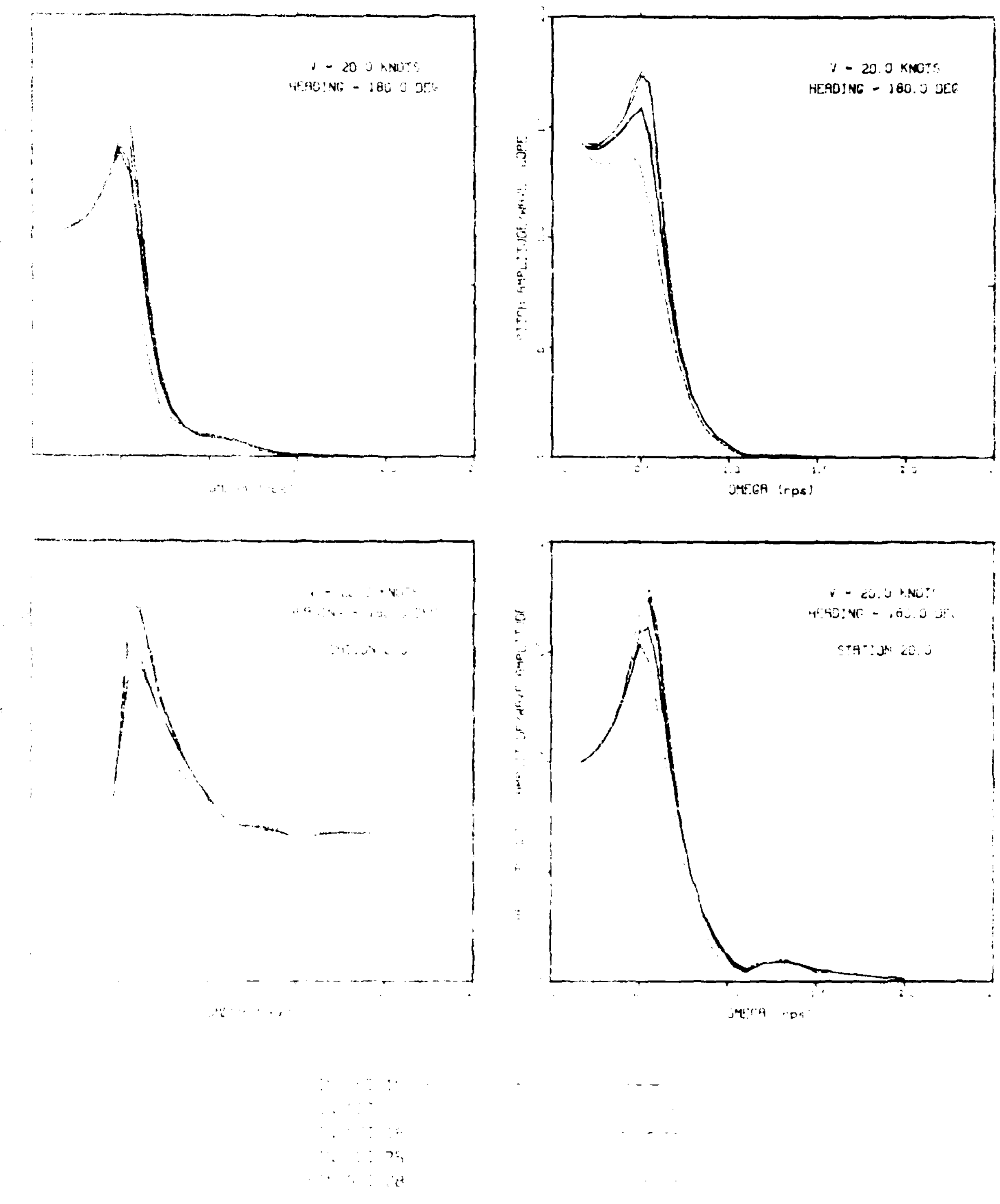


Figure 3a SWATH BB Transfer Functions in Regular Head Waves at 20 knots with Specified Fin Sets

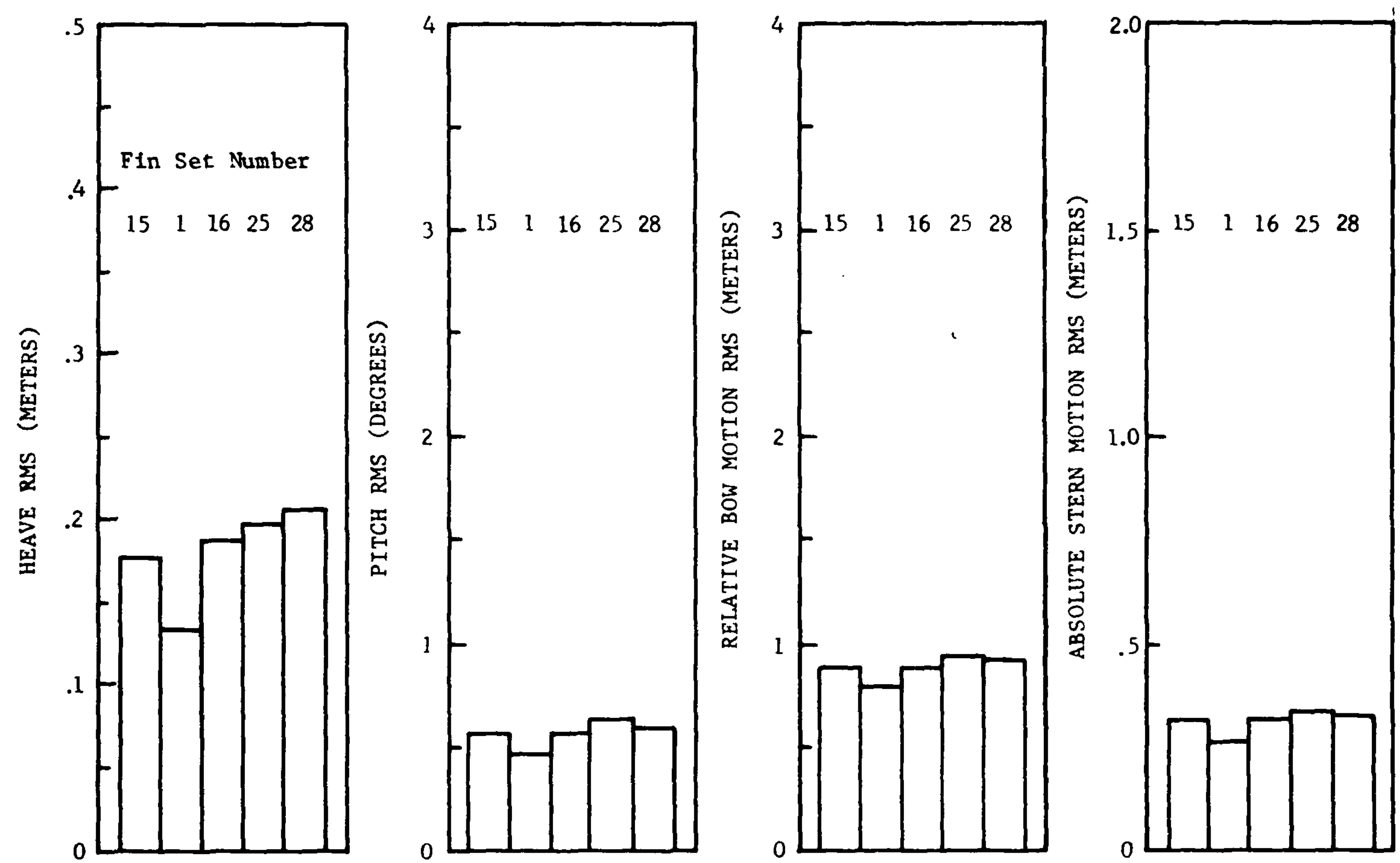


Figure 3b - RMS Responses of SWATH BB at 20 knots with Specified Fin Sets in Irregular Head Waves with Significant Wave Height of 2.4 Meters

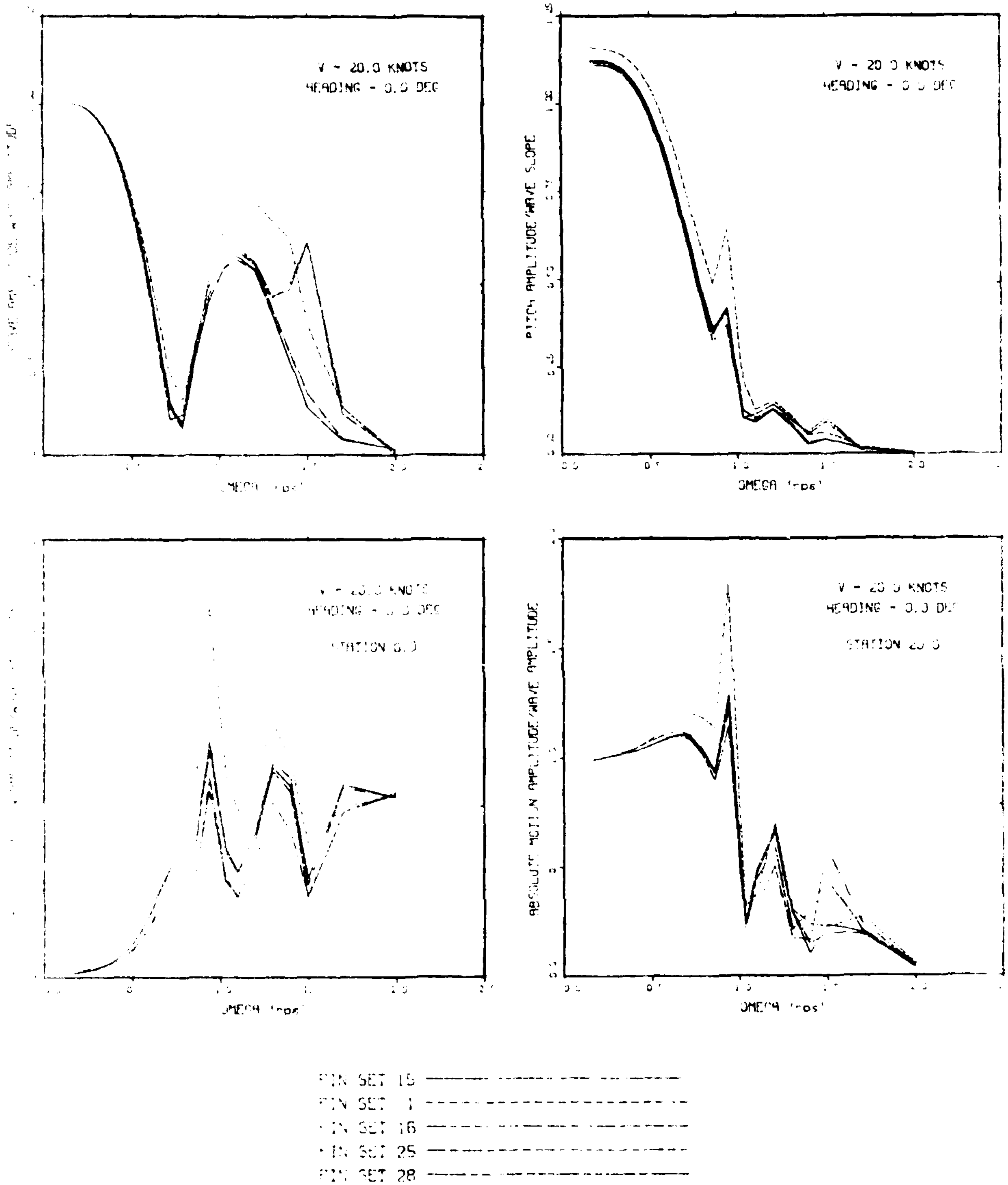


Figure 3c - **SWATH BB Transfer Functions in Regular Following Waves at** 20 knots **with Specified Fin Sets**

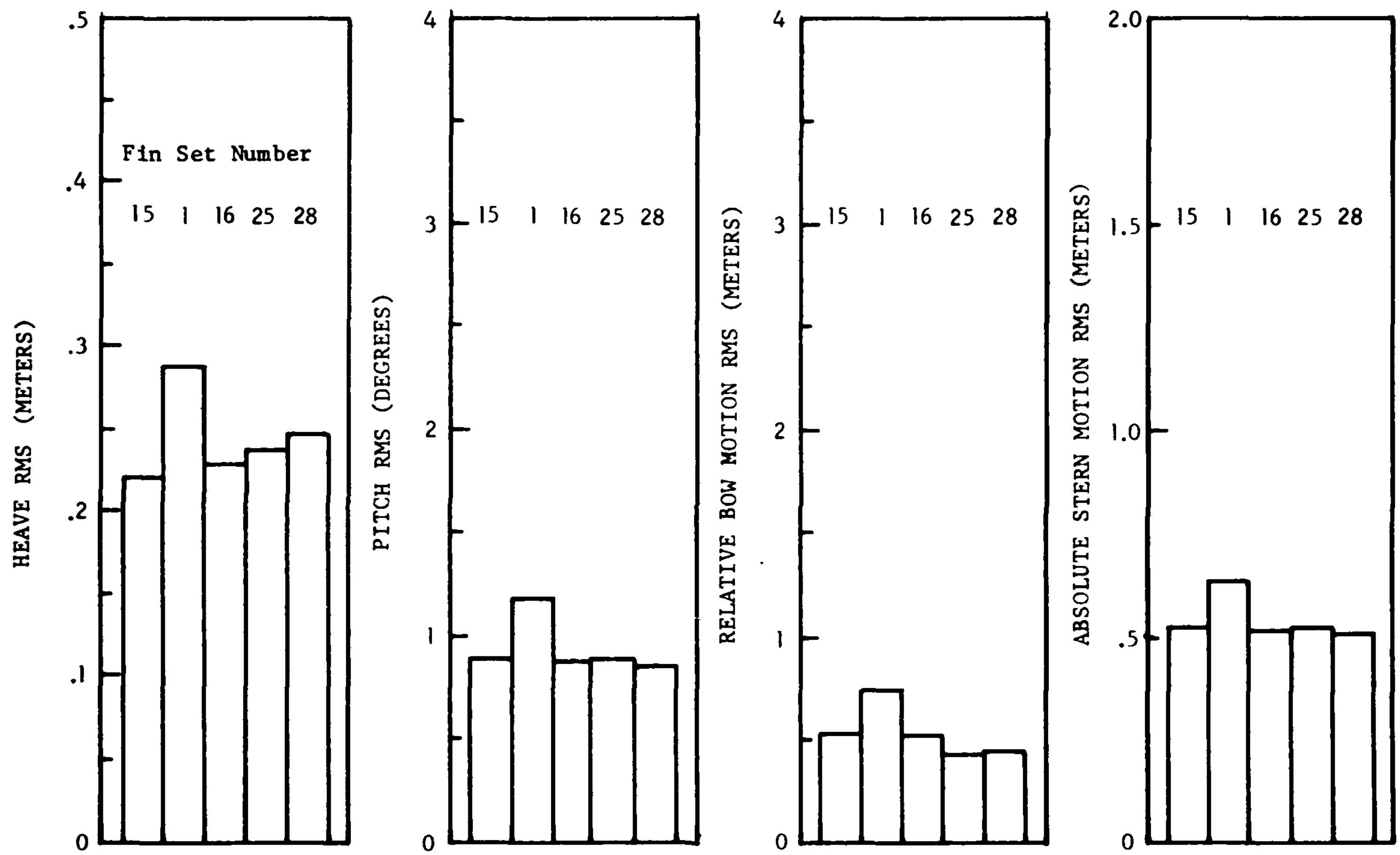


Figure 3d - RMS Responses of SWATH BB at 20 knots with Specified Fin Sets in Irregular Following Waves with Significant Wave Height of 2.4 Meters

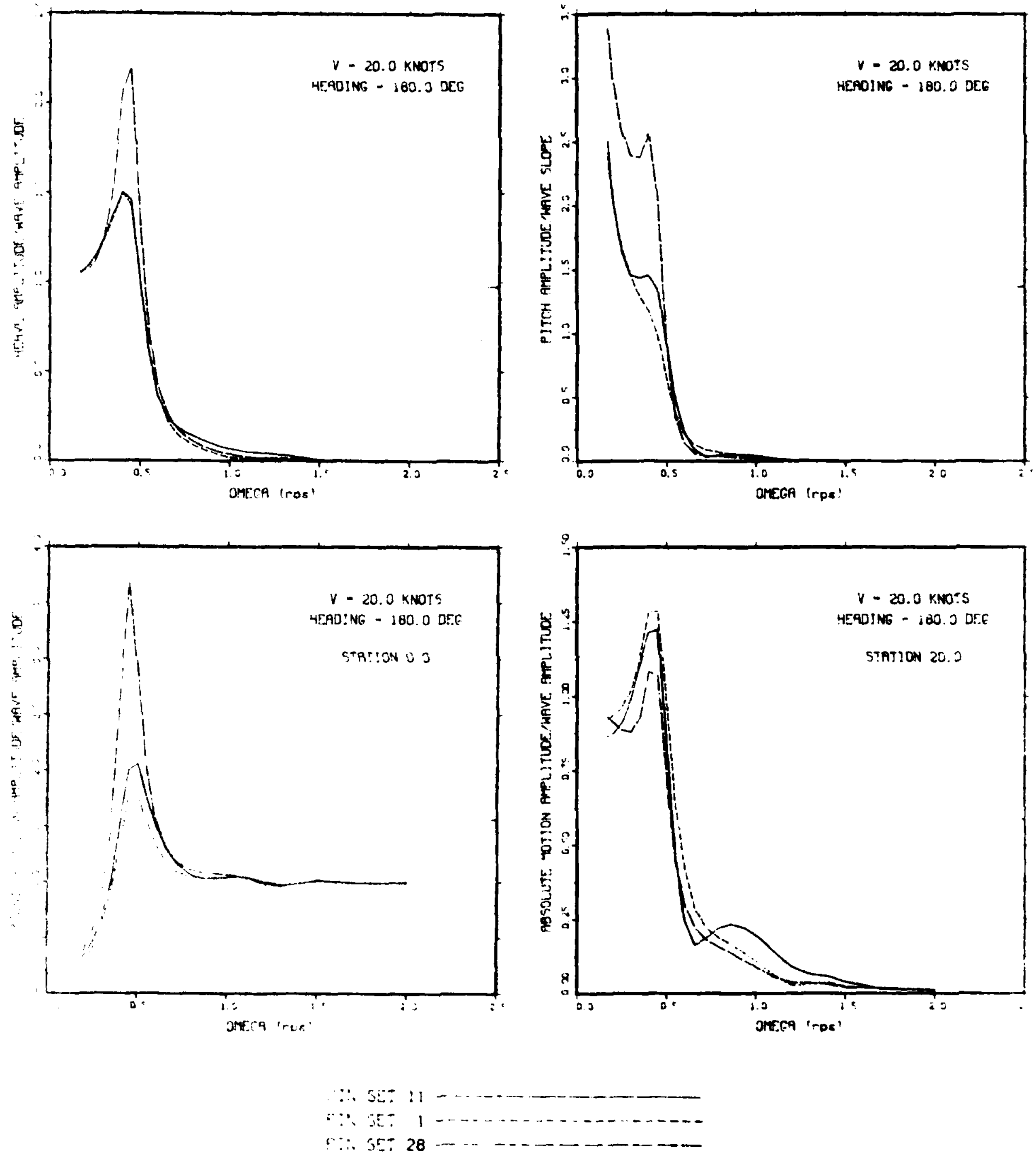


Figure 4a - SWATH CC Transfer Functions in Regular Head Waves at 20 knots with Specified Fin Sets

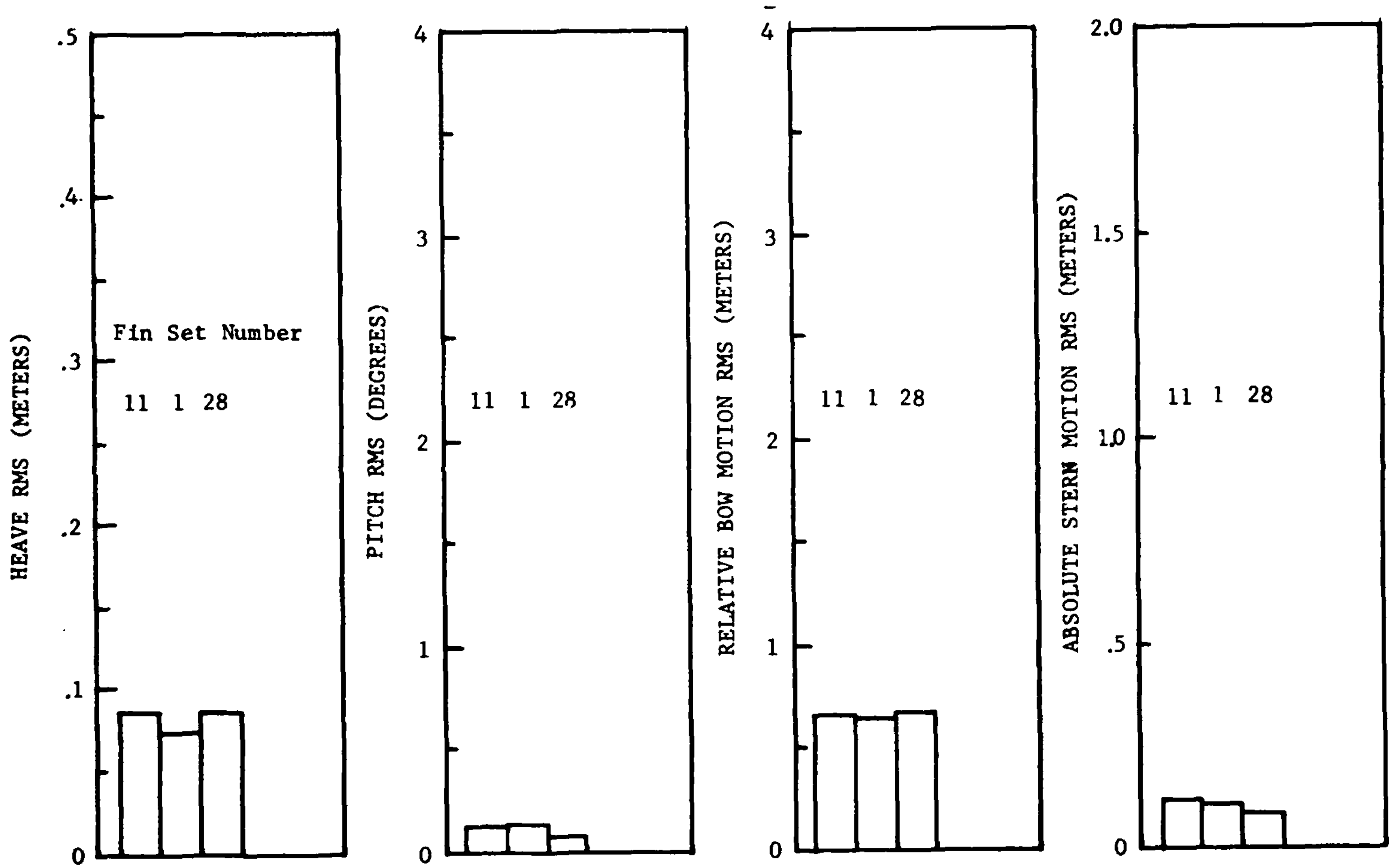


Figure 4b - RMS Responses of SWATH CC at 20 knots with Specified Fin Sets in Irregular Head Waves with Significant Wave Height of 2.4 Meters

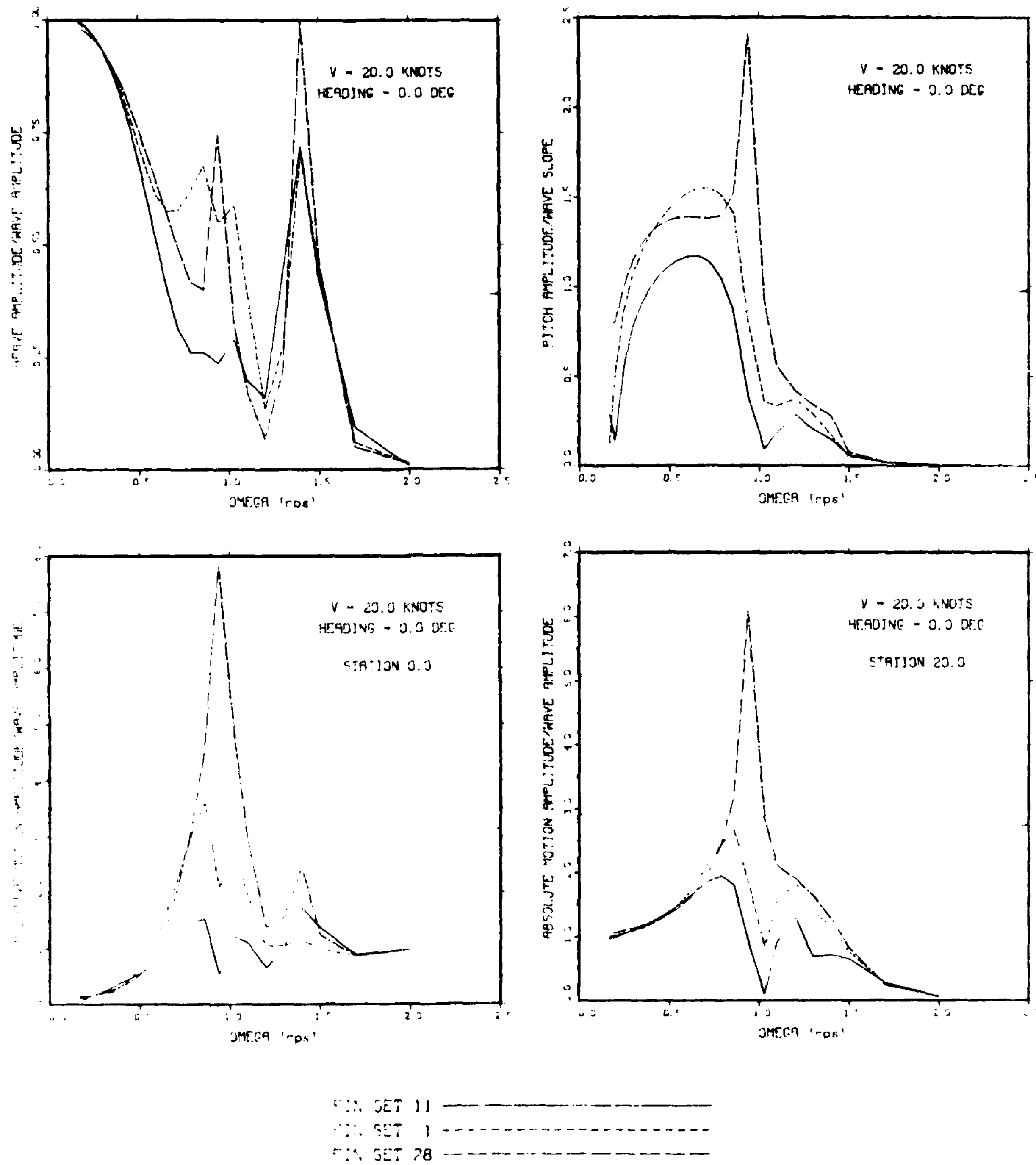


Figure 4c - SWATH CC Transfer Functions in Regular Following Waves at 20 knots with Specified Fin Sets

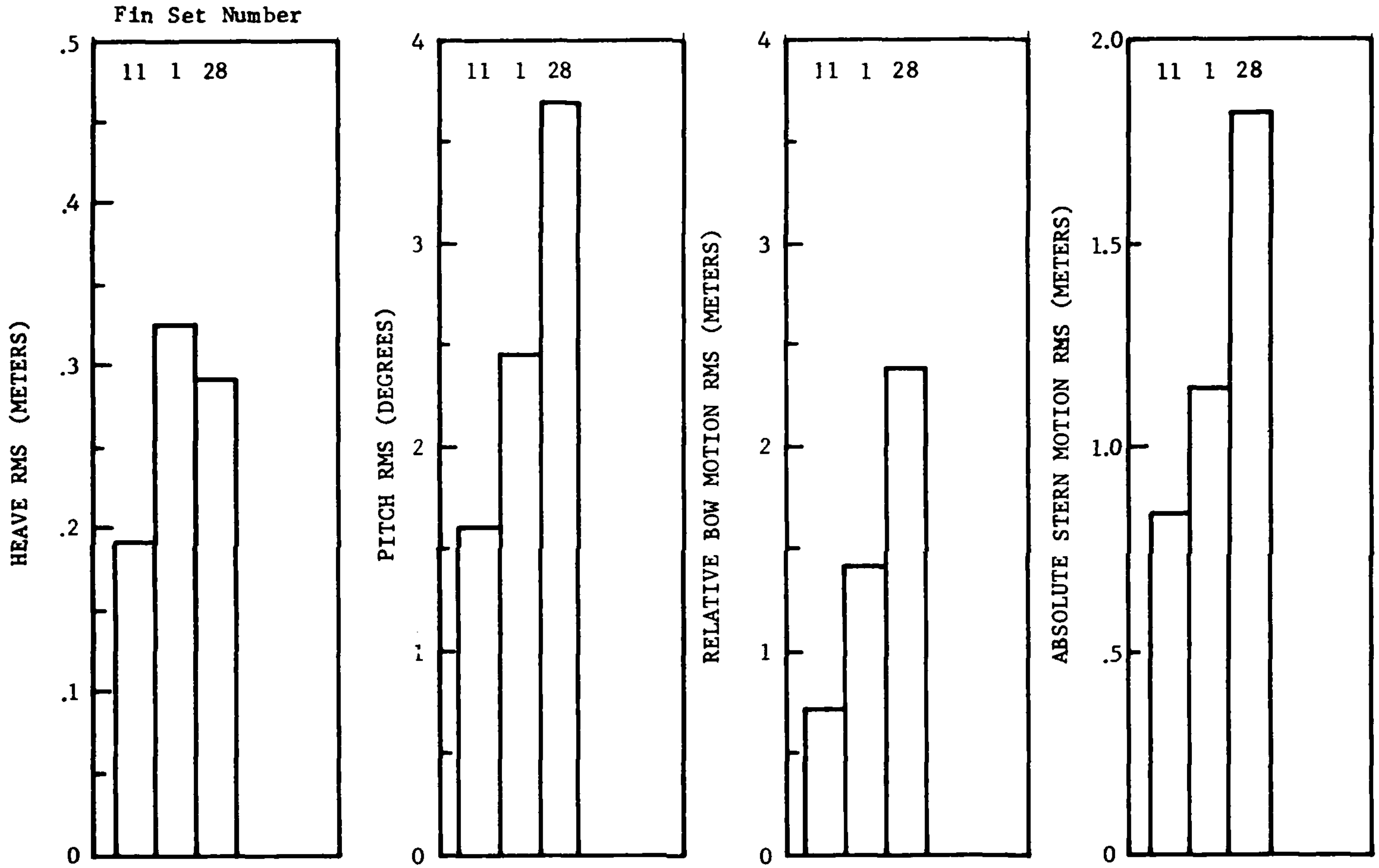


Figure 4d - RMS Responses of SWATH CC at 20 knots with Specified Fin Sets in Irregular Following Waves with Significant Wave Height of 2.4 Meters

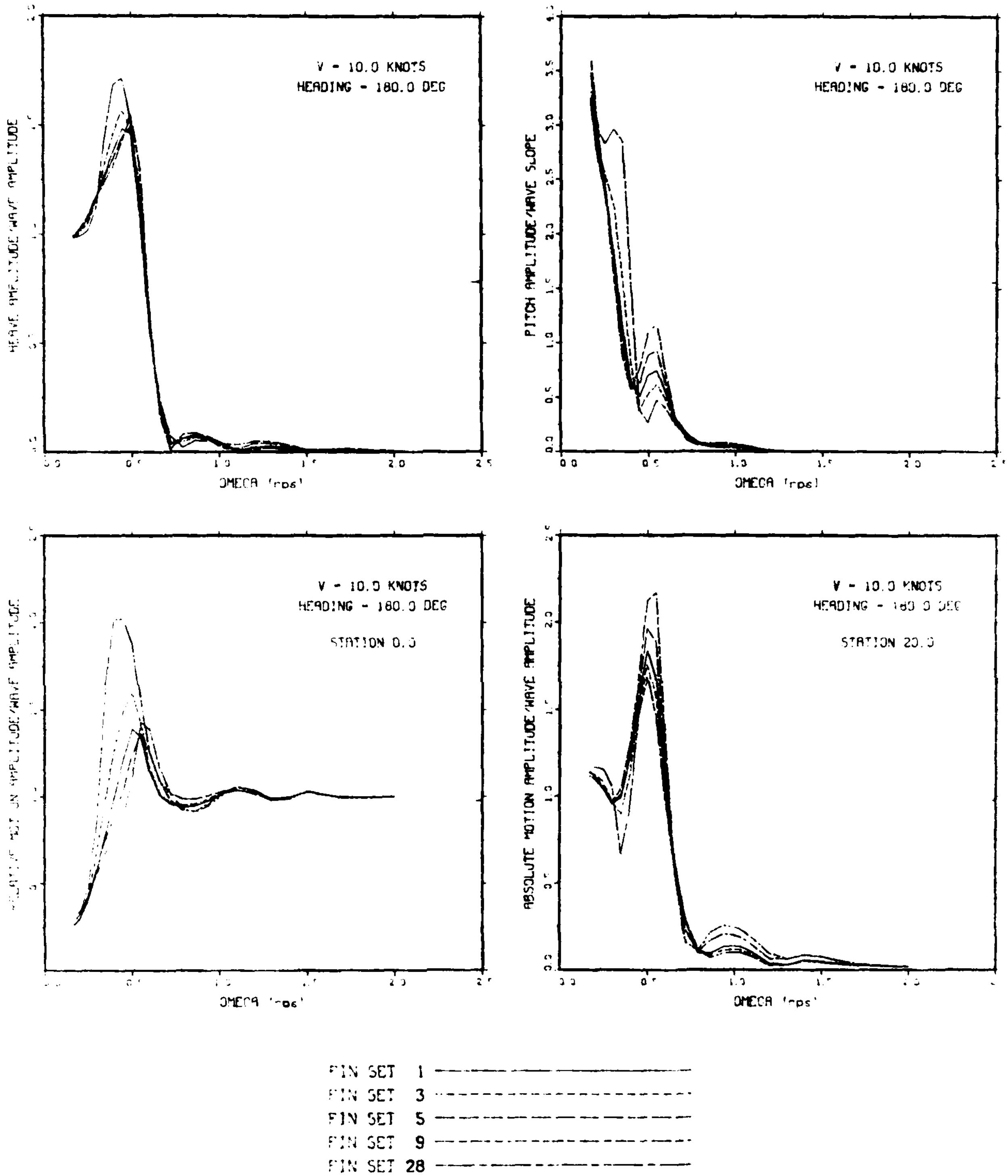


Figure 5a - SWATH DD Transfer Functions in Regular Head Waves at 10 knots with Specified Fin Sets

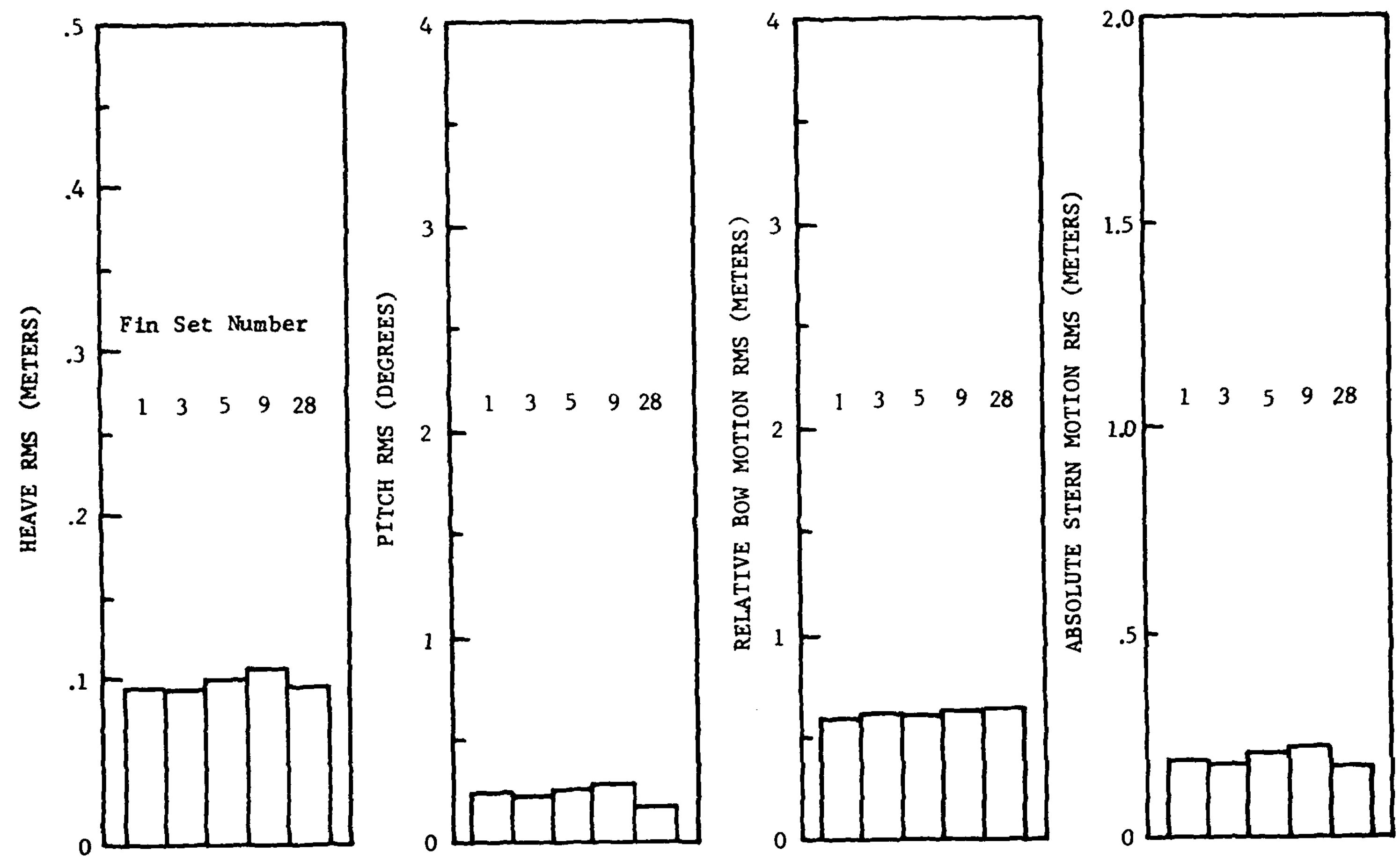


Figure 5b - RMS Responses of SWATH DD at 10 knots with Specified Fin Sets in Irregular Head Waves with Significant Wave Height of 2.4 Meters

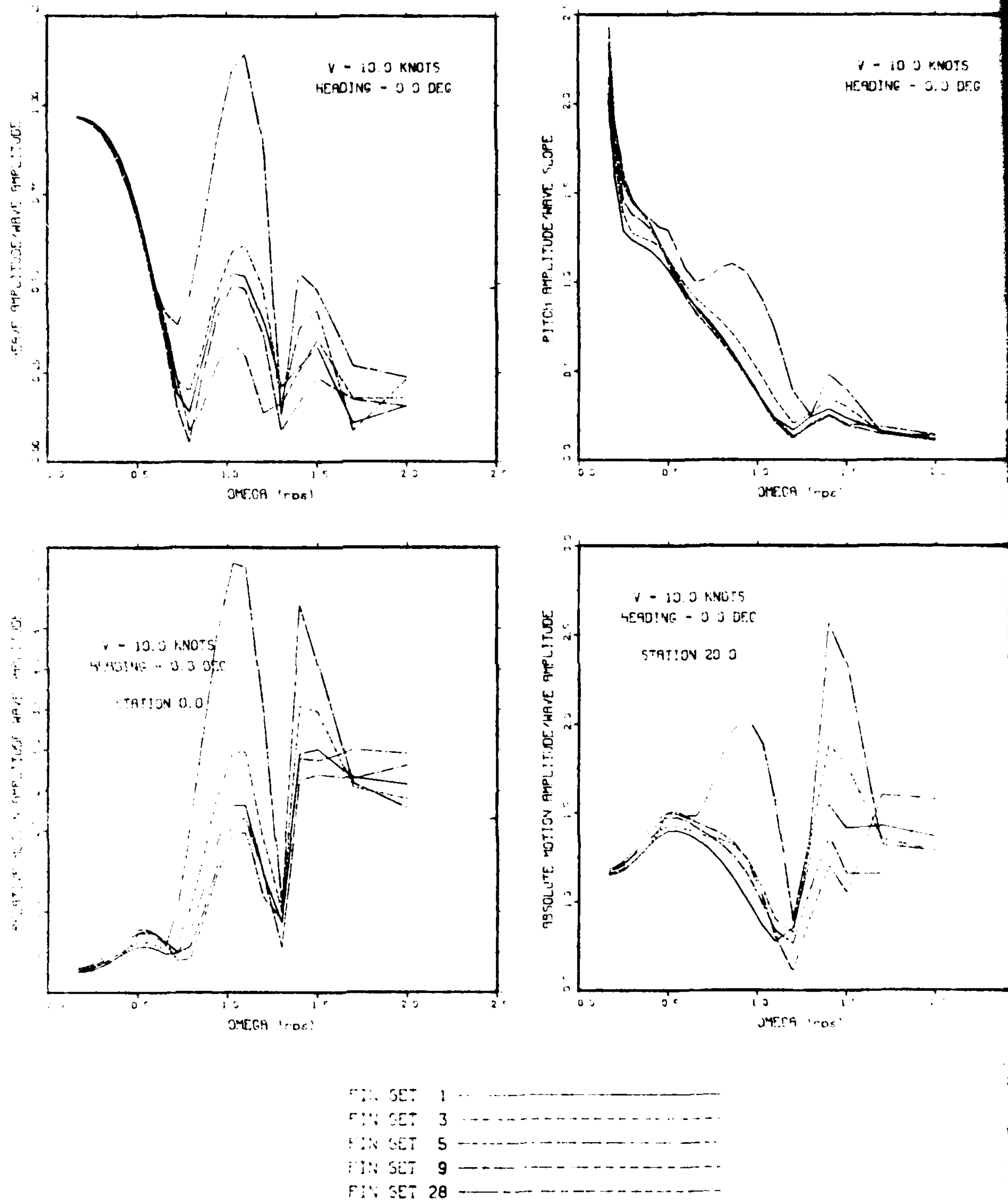


Figure 5c - SWATH DD Transfer Functions in Regular Following Waves at 10 knots with Specified Fin Sets

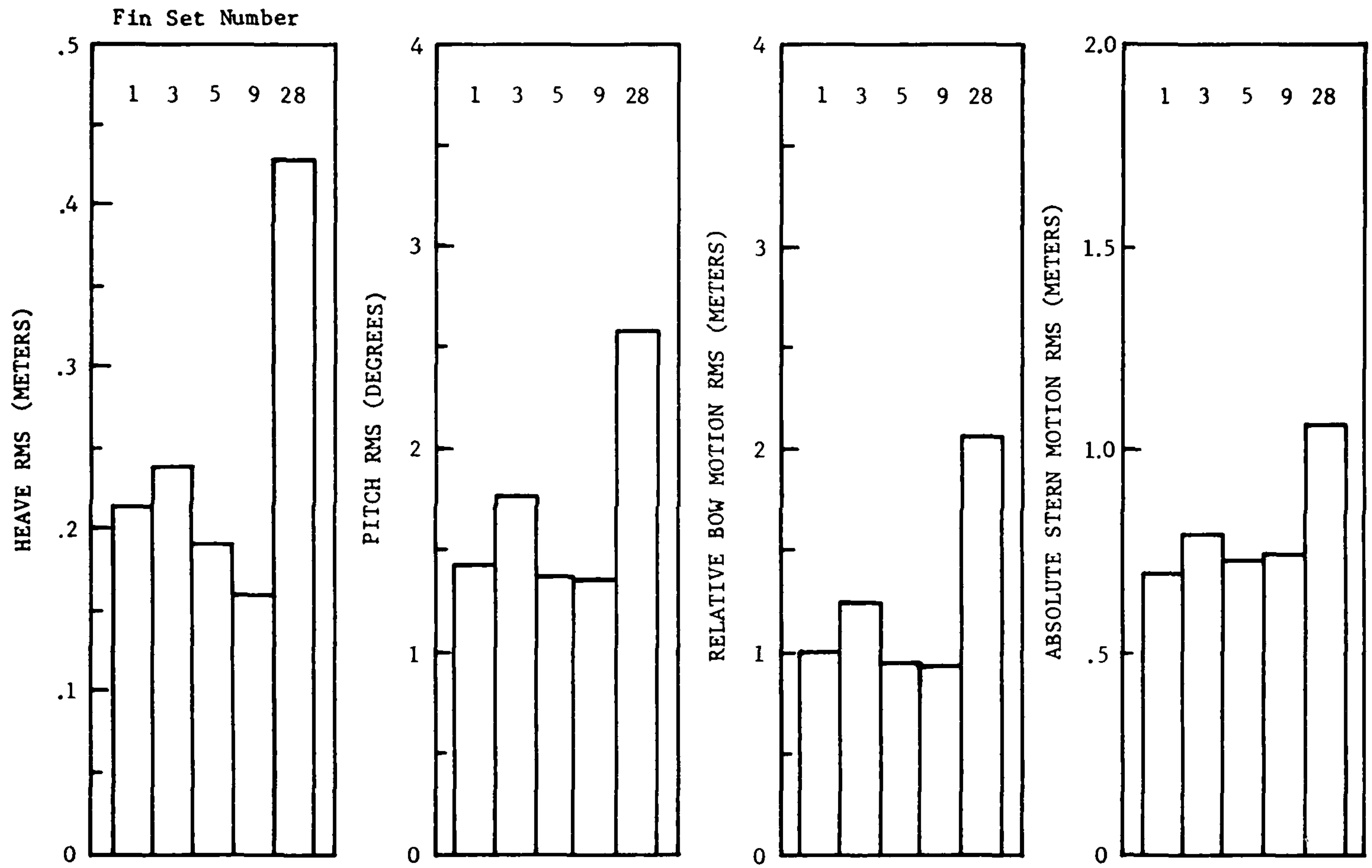


Figure 5d - RMS Responses of SWATH DD at 10 knots with Specified Fin Sets in Irregular Following Waves with Significant Wave Height of 2.4 Meters

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